FIELD PERFORMANCE OF HIGH-QUALITY AND STANDARD NORTHERN RED OAK SEEDLINGS IN TENNESSEE

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Abstract—First-year performance of high-quality (HQ), high- quality cull (HQC) and standard (ST) northern red oak (*Quercus rubra*) nursery seedlings was compared in a study established in a recent clearcut in mid-March, 2000. Objectives were to test effects of 1) seedling type, 2) planting treatment, and 3) control of competitors on the growth, browsing, and survival of planted seedlings. HQ, HQC, and ST northern red oak nursery seedlings averaging 109, 58, and 23 centimeters in height, respectively, were planted in three planting treatments: 1) row planting, 2) random spacing, and 3) inter-planting with loblolly pine (*Pinus taeda*). Three of 6 replicates for each planting treatment were chosen at random to receive competition control. Analyses within seedling types indicated no statistically significant differences between planting and competition control treatments in the first year. Differences between seedling types were much stronger. Height growth of HQ and HQC seedlings was significantly greater than that of ST seedlings. However, the incidence of browsing of HQ and HQC seedlings was also significantly greater than that of ST seedlings. Mortality of ST seedlings was significantly greater than HQC seedlings, but not significantly greater than HQ seedlings. It remains to be seen whether HQ seedlings will maintain their advantage over HQC and ST seedlings with continued browsing, and whether differences between planting and competition control treatments will strengthen as vegetation development and browsing continues.

INTRODUCTION

Artificial regeneration of oak can alleviate several problems during the early stages of regeneration such as insufficient seed sources, acorn predation, poor germination conditions, and heavy competition. Artificial regeneration with HQ seedlings can also be used to improve the quality of oak in stands where various forms of mismanagement have taken place. HQ or "super" oak nursery seedlings represent a promising alternative to ST seedlings for artificial regeneration. Seedling characteristics such as the number of coarse lateral roots and the overall size of shoots and roots are thought to be correlated with increased survival and competitive ability of oak seedlings after outplanting (Kormanik and others 1995, Kormanik and others 1997, Zaczek and others 1997). Relationships between nursery practices and these characteristics have been investigated, and protocols have been developed for producing seedlings that meet desired criteria (Kormanik and others 1994). Further, it has been demonstrated that high- and low-quality seedling grades can be distinguished visually prior to planting (Clark and others 2000). While progress has been made in defining and producing HQ oak planting stock, studies addressing the performance of different grades of seedlings are limited in number(for example Gordon and others 1995, Gottschalk and Marquis 1983, Zaczek and others 1997). Fewer still (for example Kormanik and others 1997) have documented outplanting results for HQ oak seedlings produced by the protocol developed by Kormanik and others (1994).

Potential limitations to the performance of HQ seedlings after outplanting are heavy competition with other woody vegetation and white tailed deer (*Odocoileus virginianus*) browsing. Intense competition with hardwood stump sprouts and fast-growing species arising from seed may affect the development of HQ oak seedlings, despite their large size and competitive potential (Kormanik and others 1997). Herbivory may compromise the competitive ability of any plant species (Louda and others 1990) and deer browsing can combine with heavy competition to have a synergistic, negative effect on survival. Experiences with outplanting oak nursery seedlings in Tennessee and several other regions indicate that deer have a high affinity for nursery seedlings (Buckley and others 1998, Gordon and others 1995, Kormanik and others 1995, Teclaw and Isebrands 1991). Fertilization of nursery stock may make freshly planted nursery seedlings more nutritious than the surrounding native vegetation. Controlling deer browsing is essential to establishing HQ oak plantings in areas with high deer populations. Repellants, tree shelters, and fencing methods have been developed for guarding against deer damage (Craven and Hygnstrom 1994, Nolte and Otto 1996). Unfortunately, the effectiveness of some repellants appears to depend on what other forage is available, and the costs of tree shelters and fencing can be prohibitive.

An alternative means of reducing deer browsing may be modified planting techniques that take advantage of

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relationships between deer foraging behavior, the spatial arrangement of seedlings, and structure formed by the surrounding vegetation. In prior studies conducted in Michigan, differences in the incidence of browsing of planted oak seedlings were documented over short distances with differences in vegetation structure (Buckley and others 1998). Browse damage of planted seedlings was far less frequent and intense in rows where red pine (*Pinus resinosa*) seedlings were inter-planted with northern red oak seedlings, and wherever competing vegetation partially or completely obscured a planted seedling. These observations warrant further investigation, and indicate that modification of the spatial and structural aspects of standard planting techniques may help reduce browsing losses.

OBJECTIVES

Objectives of this study were to: 1) Compare survival, growth, and browsing of 1-0 HQ northern red oak seedlings,1-0 HQC seedlings, and 1-0 ST seedlings planted in a recent clearcut in East Tennessee, 2) Investigate effects of controlling woody competitors on survival, growth, and browsing of each type of seedling, and 3) Test the viability of reducing deer browsing of planted seedlings by planting in a random pattern as opposed to a row pattern, and by inter-planting oak and loblolly pine.

METHODS

This study was established in a one-year old clearcut on the University of Tennessee Forestry Experiment Station, located near Oak Ridge in the Ridge and Valley Province of East Tennessee. All plots were located on the upper half of a north-facing slope. Site productivity was intermediate, and northern red oak formed a component of the stand prior to harvesting. Plots were laid out in an east-west line parallel to the edge of the adjoining unharvested stand (located up slope) to minimize bias in the entry of plots by deer, and spatial relationships with surrounding forest and landform features (figure 1). A 12.2 meter buffer zone was maintained between the unharvested stand edge and the upper margin of each plot (figure 1). A 7.3 meter buffer zone was maintained between all plots (figure 1.).

Six treatment combinations consisting of competition control or no competition control combined with a row planting pattern, a random planting pattern, and a row planting pattern where oak seedlings were inter-planted with loblolly pine were assigned at random to 3.7 x 16.5 meter plots (figure 1). Each treatment combination was replicated 3 times for a total of 18 3.7 x 16.5 meter plots in the study. A deer exclosure containing a row and an inter-planted plot was installed on the east end of the clearcut (figure 1) to allow comparisons of planted oak performance and vegetation development without any browsing.

Row plots contained 30 northern red oak seedlings planted in 3 rows on a 1.8 m spacing. Random plots contained 30 oak seedlings planted in a random pattern. Inter-planted plots contained 30 oak seedlings in 3 rows on a 1.8 meter spacing, inter-planted with loblolly pine seedlings. In the inter-planted rows, a 1-0 loblolly pine seedling was planted on both sides of each oak, 0.5 meter from the oak seedling stem (figure 1). All plots received 15 HQ northern red oak seedlings, 5 HQC seedlings, and 10 ST northern red oak seedlings. All seedling types were bare-root, 1-0 seedlings. HQ northern red oak seedlings from 5 genetic families were assigned to planting locations within plots in incomplete blocks to address potential interactions between slope position and performance of each family. HQC and ST seedlings were assigned to remaining locations at random. Both HQ and HQC seedlings were raised in the Flint River Nursery operated by the Georgia Forestry Commission in Montezuma, GA according to a protocol developed for producing HQ oak seedlings (Kormanik and others 1994). HQ and HQC seedlings were distinguished based on the number of first-order

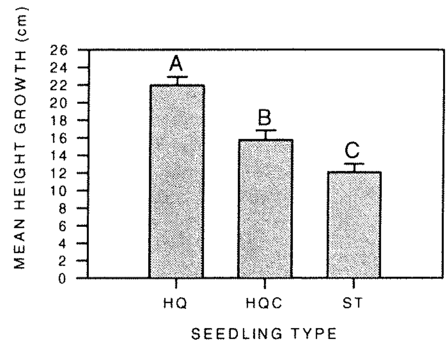

Figure 2—Mean 2000 height growth by seedling type. Means with different letters are significantly different based on ANOVA and Tukey's HSD at the $\alpha = 0.05$ level. Error bars represent 1 S.E.

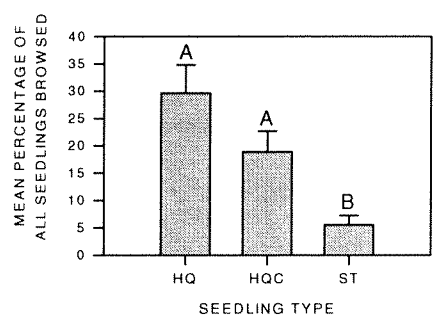

Figure 3—Mean percentage of seedlings with any type of browse damage in 2000 by seedling type. Indication of significant differences, tests, and error bars as in figure 2.

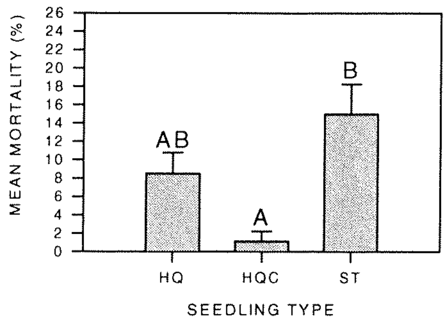

Figure 4—Mean 2000 percent mortality by seedling type. Indication of significant differences, tests, and error bars as in figure 2.

lateral roots, root collar diameter, and height (Clark and others 2000). ST seedlings were nursery-run seedlings obtained from a Tennessee nursery. Mean heights of HQ seedlings, HQC seedlings, and ST seedlings at the time of planting were 109, 58, and 23 centimeters, respectively.

Planting was completed March 20-22, 2000. Northern red oak seedlings were planted with a 20 centimeter diameter auger mounted on a 4-wheel drive tractor. Loblolly pine seedlings were planted with planting bars. No supplemental watering was used.

Woody and herbaceous competitors of oak seedlings were sprayed with glyphosate August 10-15, 2000 in all competition control plots. Oak seedlings were shielded during spraying to reduce potential damage due to drifting spray. Competition control treatments will be repeated in subsequent growing seasons.

Initial height of all planted oaks was measured between the soil surface and the tip of the terminal bud on the dominant leader. Height growth for the first growing season was determined by remeasuring heights in the same manner as described above on October 10, 2000. Seedlings were tallied for bud break and development of the first growth flush on May 5, 2000 and again on June 9, 2000. Damage due to deer browsing was recorded on June 9, July 21, and October 19, 2000. Both the presence of browsing and the type of browsing (terminal leader, lateral branch, or a combination) were documented. Mortality was recorded on the same dates as browsing. Seedlings were considered dead when shoots were completely missing, or when no live buds or green inner bark could be found on stems and at the root collar.

Preliminary analyses run within seedling types indicated no statistically significant effects of planting and competition control treatments at the $\alpha = 0.05$ level. Thus, differences between seedling types in growth, browsing, and mortality were analyzed through ANOVA and Tukey's HSD using data pooled over planting and competition control treatments.

RESULTS

Although planting and competition control treatment effects were not statistically significant, there was a trend toward slightly greater growth of HQ seedlings in plots receiving competition control. There were also trends toward a slightly lower incidence of browsing of HQ and HQC seedlings in inter-planted plots than in row and random plots, and toward greater mortality of seedlings with competition control than without.

Much stronger differences occurred between seedling types in phenology, growth, browsing, and mortality. HQ seedlings flushed later than HQC and ST seedlings. Only 62 percent of HQ seedlings had broken bud by May 5, 2000, compared with 98 and 97 percent of HQC and ST seedlings, respectively. Mean height growth of HQ seedlings was significantly greater than that of HQC and ST seedlings (figure 2). Mean height growth of HQC seedlings was significantly greater than that of ST seedlings, but significantly less than that of HQ seedlings (figure 2).

The mean percentages of HQ and HQC seedlings that had any degree of deer damage were significantly greater than the mean percentage of ST seedlings showing browse damage (figure 3). As was the case for height growth, browsing of HQC seedlings was intermediate between browsing of HQ and ST seedlings. As of June 9, 2000, 76 percent of HQ seedlings sustaining browse damage had damage to the terminal leader, while browsing of terminal leaders occurred in 100 percent of HQC and ST seedlings.

October mean percent mortality of ST seedlings was significantly greater than mortality in HQC seedlings, but not significantly greater than HQ seedlings (figure 4). Although differences between planting and competition control treatments were not statistically significant, mean percent mortality of ST seedlings was highest (30 percent) in random plots receiving competition control. Twenty-seven percent of the HQ seedlings that died and 11 percent of the ST seedlings that died had experienced browsing. The single HQC seedling that died was also browsed.

DISCUSSION AND CONCLUSIONS

Limited vegetation development, limited loblolly pine seedling growth, and low levels of browsing and competition during the first growing season may account for the lack of statistically significant differences between planting and competition control treatments. Competition between planted seedlings and other herbaceous and woody plants is expected to increase with time as stump sprouts and other vegetation continue to develop. Similarly, the impact of competition control treatments should increase as well. The 1-0 loblolly pine seedlings planted likely had little effect in shielding the larger planted oaks from browsing due to their small size. Loblolly pine seedlings were only half the height of most HQ oak seedlings during the 2000 growing season. Browsing was also lighter than expected.

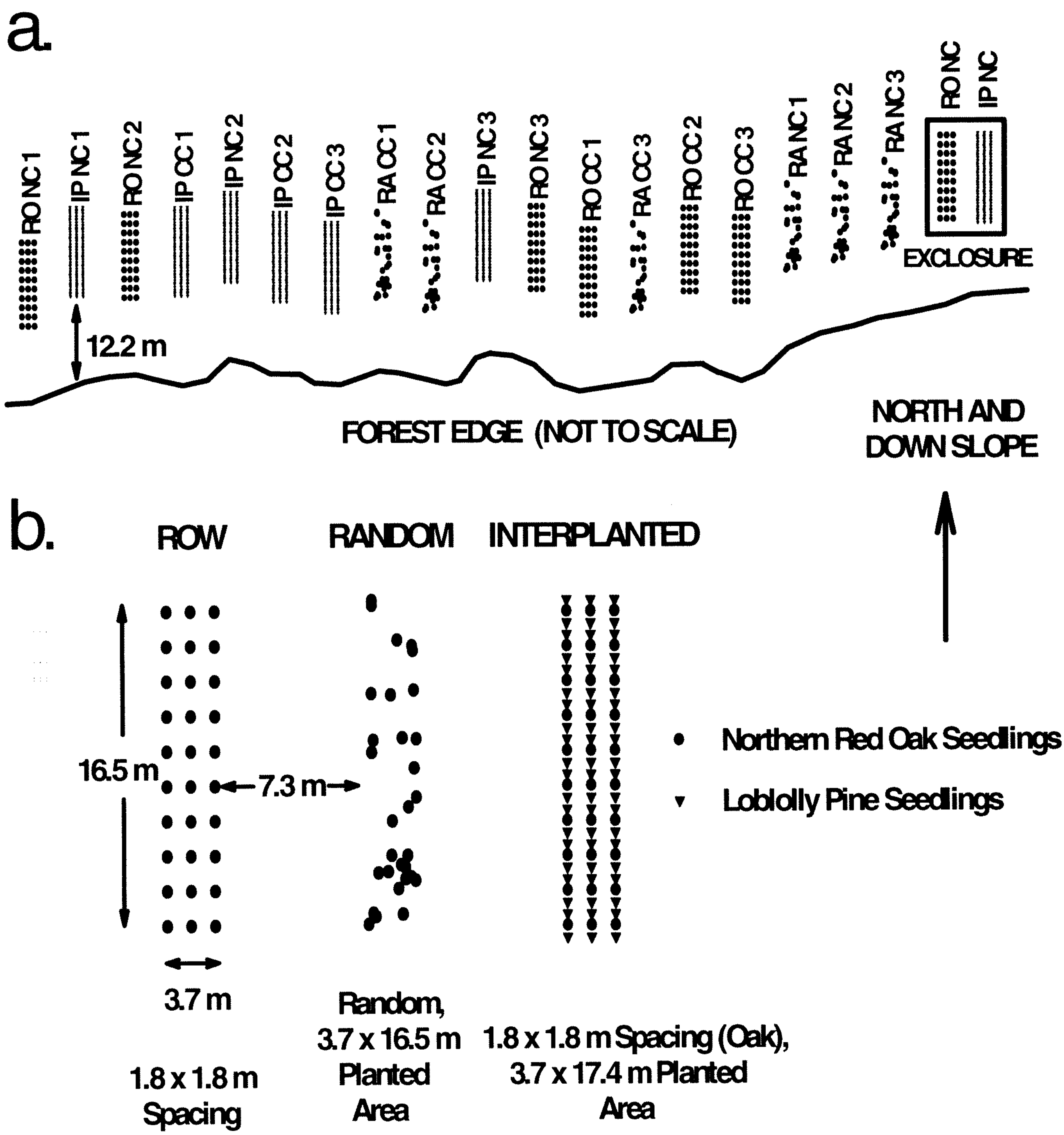

Figure 1—Layout of study (a) and planting patterns (b). RO = row, RA = random, IP = inter-planted. CC = competition control and NC = no competition control. Each plot contains 15 HQ seedlings, 5 HQC seedlings, and 10 ST seedlings.

The patterns in height growth between seedling types observed were consistent with previous predictions (Kormanik and others 1995). Mean height growth of HQ, HQC, and ST seedlings appeared to be closely correlated with seedling height at the time of planting. However, differences in nursery practices, stem diameter, the number of first-order lateral roots, and overall biomass could have contributed to these differences as well.

Differences between seedling types in the incidence of deer browsing may be related to differences in apparency and nutritional value. In contrast to ST seedlings, the shoots of HQ and HQC seedlings often extended well above competing vegetation. This difference in canopy position may have resulted in much greater apparency of HQ and HQC seedlings to deer. Similar effects of understory vegetation have been reported previously (Buckley and others 1998, Gottschalk and Marquis 1983). More frequent browsing of HQ and HQC seedlings may also be related to greater nutritional value imparted by the HQ nursery protocol.

Several factors may have contributed to seedling mortality: poor microsites, competition, browsing, and overspray of glyphosate. All seedlings were susceptible to potentially poor microsite conditions and competition prior to application of the competition control treatment. Browsing may have played a role in the mortality of a percentage of seedlings, particularly HQ seedlings. Accidental application of glyphosate killed several small ST seedlings hidden by vegetation in plots receiving competition control, particularly in random plots.

Based on first-year results, HQ seedlings appear most promising in terms of growth, although survival was greatest for HQC seedlings. The consequence of the heavier browsing experienced by HQ seedlings remains an important question. Whether these seedlings are successful in rapidly escaping the reach of deer, or whether repeated browsing will compromise their advantage over ST seedlings is unknown. Browsing may be of minimal importance on some sites, but deer populations are increasing in parts of Tennessee and elsewhere. It also unclear whether effects of planting and competition control treatments will strengthen. Long-term monitoring of seedling performance is planned.

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CONTAINER SIZE AND FERTILIZATION AFFECT NURSERY COST AND FIFTH-YEAR FIELD PERFORMANCE OF CHERRYBARK OAK

Kirk D. Howell and Timothy B. Harrington[1]

Abstract—Successful regeneration of bottomland hardwoods relies on the production of vigorous, plantable, and affordable stock by commercial nurseries. To quantify nursery cultural influences on subsequent field performance of cherrybark oak (*Quercus pagoda* Raf.), seedlings were grown in a greenhouse in small, medium, or large containers for three months with or without fertilization. In December 1994, seedlings were planted at a bottomland site near Milledgeville, GA with or without removal of the container soil as a method to reduce transport and planting costs. Estimated costs per thousand seedlings for these practices were about $1225, $560, and $185 for large, medium, and small containers, respectively. A 30 percent profit margin was added to each price. The incremental cost of fertilization per thousand seedlings was about $12, $6, and $2 for large, medium, and small treatments, respectively. Cost savings from container soil removal were substantial for the large containers, and savings decreased with decreasing container size. Five years after planting, survival of seedlings from large containers (97 percent) was significantly greater than that from small containers (85 percent). Soil removal was associated with reductions in seedling survival, but only in the absence of fertilization. Stem diameter and height of seedlings from small containers were less than those of seedlings from medium and large containers, and they were also significantly greater in the presence versus absence of fertilization. Fifth-year seedling size did not vary significantly between levels of soil removal. Nursery and fifth-year cost efficiencies were greatest for fertilized, soil removed, medium containers and for fertilized, small containers.

INTRODUCTION

Large seedlings are recommended for successful artificial regeneration of oak (Ruehle and Kormanik 1986), but high cost and difficulty of planting them can greatly limit cost effectiveness and applicability of this method of regeneration. Poor performance of planted oaks probably reflects the need for improvements in both nursery and planting technology. It is one thing to grow an ideal oak seedling to a sapling size in one or two years, but then to correctly plant the proportional root mass can impose quite the endurance test (Bowersox 1993). Planting speed and quality under these conditions can be compromised, especially when specifications require holes in difficult soils greater than 15 centimeters depth. Large seedlings with proportionately sized root systems cannot be correctly and efficiently planted unless they are undercut at lifting, root-pruned at the time of planting, or the planting hole is of sufficient size to accommodate the extensive root system. Unless root alteration is performed, planting seedlings with roots larger than the hole will result in either root deformation (Haase *et al.* 1993) or root desiccation because of shallow planting.

The field applicable alternative may best be found in root confinement, rather than in root alteration -, i.e., growing seedlings with root systems designed to fit the planting tool, instead of reducing the size of the root system to accommodate the planting tool. The former attempts to prevent rooting excess, while the latter attempts to correct the problem. Containerized seedlings have shown success in survival and growth, and a further incentive of root confinement should be to facilitate the planting of large stems. Another incentive for containerizing seedlings is to permit managers to plant late into the season, and to maintain more of a three-dimensional root configuration after planting.

It is not clear how containerized seedlings will fare when planted as bareroot stock, or how such procedures will affect cost of planting or nursery production. In an attempt to address these issues, a study on cherrybark oak was initiated to compare field performance, associated costs of nursery production and planting, and cost efficiency of among treatments that included differences in container size, nursery fertilization, and removal of container soil at the time of planting.

MATERIALS AND METHODS

In a greenhouse on the University of Georgia campus, Athens GA, seeds of cherrybark oak were sown July 1994 in small, medium, or large containers (3.5, 6.5, and 11.5 centimeter diameters, respectively) and grown for 3 months. A randomly selected half of the seedlings received a weekly fertilization treatment with a water solution of 20N 20P 20K. A total of 100 seedlings were

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cultured for each of the six treatments (three container sizes x two fertilization levels). In October 1994, seedlings were moved to an open-air enclosure to stimulate the onset of dormancy. The planting site, a 0.1-hectare area fenced to prevent deer browse, is located on an abandoned field in the lower flood plain of the Oconee River near Milledgeville Georgia. Competing vegetation was suppressed with a broadcast application of a 2 percent water solution of Accord® (glyphosate) herbicide in July 1994. Prior to planting, seedlings were randomly assigned to either removal or retention of container soil as a test to reduce transport and planting costs. In December 1994, seedlings were planted with a hoedad at a spacing of 0.5 x 1.8 meters. The experimental design is completely randomized with three replications of 13 seedlings for each of the twelve treatments, a total of 468 seedlings. Survival, basal stem diameter, and height of each seedling were measured one, two, three, and five years after planting. A per-hectare value of total stem volume (cubic decimeters) was calculated for each treatment replication assuming a planting density of 750 seedlings per hectare.

The retail price required to produce a thousand seedlings was estimated for each treatment using real cost information from an undisclosed nursery. The price equaled the seedling cost at planting plus the cost of planting. We assumed a nursery that contained 7500 square meters of production space (15 greenhouses). Container diameter determined capacity of container production. Fixed costs, including salaries, insurance, dues, research and development, land, buildings, and supplies, were assumed to be influenced by greenhouse capacity. Treatment-related costs included fertilizer and application costs, labor and materials for packaging, transport and storage of seedlings as affected by container size, and labor and materials associated with container soil removal. The price per thousand seedlings included 30 percent profit. Field costs, such as the purchase price of land and costs of site preparation, were not included in this analysis. Costs were compounded for five years assuming an eight percent interest rate. The ratio of nursery cost (dollars per hectare of planted seedlings) to stem volume yield (cubic decimeters per hectare) was calculated to provide an index of cost efficiency.

RESULTS AND DISCUSSION

In the nursery, we achieved almost 100 percent stocking of growing space. Five years after planting, survival of seedlings from large containers (97 percent) was significantly greater than that from small containers (85 percent). Unfertilized, soil intact seedlings were also significantly lower in numbers (83 percent) as compared to the other treatment combinations, which is to be expected from nutrient deficient seedlings, but these results seem counterintuitive since the soil was left intact. From the nursery, fertilized seedlings from large and medium containers were significantly greater in diameter (4 millimeters), height (32 centimeters), and yield (2.2 cubic decimeters per 1000). Seedlings from the large and medium container sizes remained significantly larger than those from small containers by year one, and as expected, fertilized seedlings remained significantly larger than those not fertilized. By year five, fertilized seedlings from large and medium containers remained significantly greater in diameter (43 millimeters), height (338 centimeters), and yield (1.84 cubic meters per hectare). Initial stem diameters (< 5 millimeters) and heights (< 50 centimeters) were smaller than those currently recommended for artificial regeneration (Ruehle and Kormanik 1986).

Full stocking of growing space in the nursery seedbed or in the field is critical if costs are to be minimized. Increasing seedbed density or maintaining survival favors the cost side of the equation. All fixed costs (wages, salaries, investments, etc.) were to be recovered in the pricing of the product. The fixed costs to grow 600,000 stems in large size containers carried a relative charge per thousand seedlings of $1003, $451 to grow 1,333,000 stems in medium size containers, and $142 to grow 4,267,000 stems in small size containers. Since there was near 100 percent stocking in the nursery, the quantity sown was the quantity harvested. If stocking had been less, nursery fixed costs would have increased to cover this shortfall.

Variable costs, also affected by the quantity supplied, were most influenced by fertilization and soil removal. Fertilization had little impact with values of $12, $6, and $2 per 1000 seedlings for large, medium, and small treatments, respectively, representing the combined supply and application costs of fertilization. Regardless of the capacity, the cost of fertilization is a small price to pay for the yield increase resulting from it. Soil removal, on the other hand, displayed the greatest cost impact on materials saved. Soil and amendment costs were calculated by determining the cost required to replace either 100 percent of the material (soil intact), or 10 percent of the material (soil removed) every year for each container size treatment. At $1 for every 50 pounds of material, the relative costs figured to be $28, $30, and $24 per 1000 seedlings for large, medium, and small soil intact treatments, respectively, but only 10 percent of these costs were charged when soil was removed. The assumption is that sterilized soil and amendments will be reused from year to year in the soil-removed situation, and only 10 percent of which needs to be replaced.

Seed sowing costs were affected by the time required to sow seed into containers. Relative times in seconds to prepare and fill 20 containers with soil and to sow seed were about 320, 200, and 120 seconds for large, medium, and small containers, respectively, which translates into a sowing cost of $45, $27, and $18 per thousand, respectively. The rate of pay to the laborer was determined to be $10 per hour, and this wage remained the same with all operations involving the use of time.

Nursery transport costs were calculated according to the amount of time required to move a load 100 feet in three minutes, and transporting in the nursery was performed in two trips (from the head house to the greenhouse position after sowing, and from the greenhouse to the packing house at harvest time). The cost per 1000 seedlings to move large containers was calculated to be about $56 with nine containers per trip, about $25 with 20 medium containers per trip, and about $10 with 50 small containers per trip.

Packing materials were affected by the relative size of seedlings and whether or not soil was left intact. The amount of seedlings to equal 30 pounds was the criteria utilized, and thus the heavier the seedling, the larger the quantity of bags required. The cost of bags ($1) includes the costs involved in the packaging operation. All soil removal treatments, regardless of container size, carried a similar bag charge (about $2 per 1000 seedlings), with an average of 500 seedlings per bag. However, packing costs with heavier, soil intact seedlings were about $80 per 1000 seedlings for the large, $39 for the medium, and $10 for the small container sizes.

The total nursery costs (fixed and variable) were figured to be about $1225, $560, and $185 per 1000 seedlings for large, medium, and small containers, respectively. With the additional 30 percent profit margin included for pricing each treatment, the values increased to about $1590, $730, and $240 per 1000 seedlings for large, medium, and small containers, respectively. Prices became the relative costs of the seedlings purchased for planting. Thus, to express seedling price per hectare, reduce the nursery seedling price by 25 percent (assuming 750 stems per hectare).

The planting operation involved the cost of carrying seedlings to their respective positions to be planted (determined by the weight of the load) and the time (seconds per seedling) it required to plant them. Each of these integrated tasks (involving weight and time) in the planting operation was equally allocated. The wage paid to the worker in the field was $15 per hour, as opposed to the $10 per hour nursery wage. Each soil removal treatment, regardless of container size, carried similar costs for planting, with a fifth year of compounded cost of $25 per hectare. Treatments with soil left intact, however, constrained the planting operation to differ greatly with container size, with fifth year costs of about $139, $85, and $34 per hectare for large, medium, and small container sizes, respectively. Removing soil from the seedlings of small container does not offer the same reduction in planting costs as it does from those seedlings of medium and large containers.

There were other plantation costs that could be assessed, e.g., site preparation and land costs, but these types of costs were not factors in our study because they had no influence on our treatments. Therefore, total fifth-year plantation costs, involving only the cost of seedlings and planting them, were about $1335, $630, and $220 per hectare for large, medium, and small container sizes, respectively.

The nursery treatments having the greatest cost efficiency were those of medium, fertilized, soil removed ($277 per cubic decimeter), and small, fertilized ($247 per cubic decimeter). Fifth-year results indicated similarly the lowest values of cost efficiency for fertilized, soil removed, medium containers ($285 per cubic meter), as for fertilized, small containers ($272 per cubic meter). It is interesting to note that the large, fertilized, soil removed treatment by year five was great enough in yield (2.47 cubic meters per hectare) to overcome a relatively large seedling and planting cost ($1261 per hectare), and displayed a cost efficiency ($510 per cubic meter) almost equal to that of the unfertilized, small containers ($468 per cubic meter). This illustrates how excellent seedling performance from expensive seedlings can, after five years, "catch up" with inexpensive seedlings that have lagged in growth.

CONCLUSION

Successful artificial oak regeneration involves many factors that carry both cost and yield implications. Representation, both in the nursery and in the field, is a critical factor which deals with the quantity supplied to the market, dictating the price to be attached to the product (Tomek and Robinson 1990). The productivity of an operation, which we have attempted to demonstrate here, can be increased by: 1) increasing seedling density in the allocated space; 2) improve percent emergence after sowing; and 3) maintain high survival percentages after germination or after planting in the field. However, It has been shown in this study, as in others (South 1993), that stem diameter is typically reduced when seedlings are grown at high densities, and this has an impact on long-term plantation success.

The quality of the product, other than the genetic properties, was expressed in terms of seedling size or stem yield (i.e., proportional allocations of mean diameter and height were described in the stem volume equation), but quality cannot be completely evaluated without attempting to evaluate the entire process of production. Stem yield is much easier to describe and evaluate statistically, than is the estimation of the costs associated with production, which may explain why cost accounting is often avoided. This is acceptable when the study is strictly biological. In this study of applied science, however, hypothetical cost estimation involved many cost assumptions (e.g., costs of labor, nursery space, supplies, etc.). Assumptions can be most credible when derived from empirical operations, and our estimates for each treatment utilized real cost information from an undisclosed nursery. It was where no operation or empirical data exists that values must be derived from factors of time, volume or weight. Valuation must be revised, therefore, from time to time, place to place, and according to current knowledge.

While the small and medium, fertilized treatments were optimum in cost efficiency, the large, fertilized, soil removed treatment showed great promise in overcoming the excessive costs. The cherrybark oak benchmarks established here have shown fifth-year yield results that could arguably be considered morphologically eight years old according to plantation standards (Kennedy 1993), or ten years old when grown under natural conditions. Moreover, this benchmark offers a challenge to future research to produce the same or better yield, and also to eliminate any extreme costs attached to production (Howell 2002). We have yet to accurately and completely test the limits of nursery and plantation cost efficiency.

When one wishes to compare studies from place to place or from time to time, other costs pertinent to production must be evaluated. Protecting the seedlings in our study was cost prohibitive in practice (several thousand dollars per hectare depending on the materials used), and the inclusion of costs like this can dilute the gains perceived. Nevertheless, one could argue that expensive, and perhaps non-applicable, methods must be eliminated to promote large-scale regeneration of cherrybark oak.

As natural oak stands are depleted and the demand for oak products rise, there will be an increased emphasis toward higher productivity on a given land base. If land owners or managers are to invest in the oak stand, confidence must be established that vigorous stems will be efficiently purchased and planted, that costly procedures will not be required to ensure survival, and that steady growth will secure high future stem yield and plantation success.

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EFFECT OF SEEDLING SIZE AND FIRST-ORDER LATERAL ROOTS ON EARLY DEVELOPMENT OF NORTHERN RED OAK ON A MESIC SITE: ELEVENTH-YEAR RESULTS

Paul P. Kormanik, Shi-Jean S. Sung, Donald Kass, and Stanley J. Zarnoch[1]

Abstract–The effect of initial first-order lateral root (FOLR) groupings of northern red oak (*Quercus rubra*) seedlings on a high quality mesic site was followed for eleven years on a shelterwood and a clearcut area. The initial FOLR number groups were empirically determined as low (0 to 6), medium (7 to 12), and high (12). The shelterwood overstory was removed before the beginning of the eighth growing season and a circle (0.9 meter radius) was released around individual oaks in the clearcut. Individuals in the clearcut responded favorably to release, with some obtaining 6 to 8 meter in height by age 11. After the same period mean height from the shelterwood plantings was about 60 centimeter more than their initial height in 1990. It appears that large thrifty northern red oak seedlings can be established in properly controlled clearcut areas provided post harvest control of stumps is completed in a timely fashion. The shelterwood system with artificial regeneration does not appear to be a viable regeneration alternative as tested here.

INTRODUCTION

The basic tenets for northern red oak (NRO) (*Quercus rubra*) regeneration have been described by Sanders (1971, 1972). Working on lower quality sites in the central states, he clearly established that successful regeneration depended almost exclusively on the presence of advanced oak reproduction when the mature stand was harvested. On sites where the research was completed, faster growing competing species were a minor problem at best. However, obtaining the necessary advanced oak reproduction proved to be time consuming and difficult. Research after Sanders' was directed at various methods of obtaining adequate advanced reproduction by attempting to combine both natural and various combinations of artificial regeneration (Johnson 1993, Loftis 1983). This later research was applied to high quality mesic sites as well as sites comparable to those on which Sanders' research was completed. The use of the shelterwood system to encourage the development of advanced natural regeneration became the norm on these higher quality sites as clearcutting in any form became vilified by many uninformed individuals. In addition, various combinations of root/top pruning of nursery stock were extensively tested to improve their growth performance and, to increase the number of NRO after shelterwood was removed.

Eventually, it became apparent that competition from faster growing species made it very difficult to maintain a viable presence of NRO on the desirable mesic sites and NRO's future on these sites became questionable (McGee and Loftis 1986). Kellison (1993) most recently suggested that if new technology was not soon developed then NRO may become the "California Condor" of the eastern deciduous forests.

The initial objective of this research was directed at determining whether the nursery fertility protocol developed at our research center could produce "advanced oak regeneration" in the nursery in a single growing season. A secondary objective was to determine if a first-order lateral root (FOLR) grading systems previously used for sweetgum could be modified to select the best oak seedlings for outplanting in both a clearcut and shelterwood operation on a high quality mesic site.

METHOD

Two adjacent areas on the USDA Forest Service's Grandfather Ranger District on the Pisgah National Forest, 12 miles northwest of Marion, NC, were used in this study. The site index for yellow poplar (*Lirodendron tulipfera*) was approximately 100 (base age 50). The main crown canopy was a mixture of northern red oak, white oak (*Q. alba*), red maple (*Acer rubrum*), and yellow poplar. The clearcut area to be used for NRO enrichment planting was a small segment of a larger harvested area. The shelterwood area

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was immediately across the road from the clearcut area and had essentially the same species composition. For the underplanting, basal area was reduced by 30 percent to 20.44 meter^2/hectare, primarily by removing the intermediates and suppressed trees from the canopy level and all individuals occurring in the subcanopy level.

Acorns were collected from the Forest Service's Wataqua Seed Orchard in eastern Tennessee. The seedlings were grown at the Institute of Tree Root Biology's (ITRB) Whitehall Experimental Nursery, Athens, GA during the 1989 growing season, using a hardwood nursery protocol (Kormanik and others 1994). The seedlings were lifted during February 1990 and outplanted in March 1990. When lifted, the seedlings were placed in one of three groups, low, medium, and high, based upon FOLR numbers. First-order lateral roots were defined as roots with basal diameter exceeding 1 millimeter along the first 30 centimeter of taproot below the root collar. The low, medium, and high groups had FOLR numbers of 0 to 6, 7 to 11, and 12, respectively. Root collar diameters (RCD) and heights were recorded for each seedling. Each lateral root was trimmed to approximately 15 centimeter and taproots were pruned to 30 centimeter before seedlings were outplanted.

The clearcut and shelterwood areas were each considered as randomized block design. Eight blocks were laid across the contour in each of the two areas and 10 trees from each FOLR group were shovel planted at 1.5 meter by 3.1 meter spacing in adjacent rows. The spacing was maintained with only minor adjustments due to large stumps. All standing trees, regardless of size in the clearcut area were felled before planting but no subsequent vegetation control measures were taken until the seventh growing season. Mechanical control in the shelterwood area removed all subcanopy trees as well as specific canopy trees overlapping naturally regenerated northern red oak seedlings on the periphery of the planted area. No subcanopy oak was present, but none of the naturally regenerated oak in the main canopy was removed when shelterwood was established. No statistical analyses were performed to compare clearcut with shelterwood because each was an independent randomized block experiment. In addition, no statistical comparisons were done for FOLR groupings due to the presence of stump sprouts and different degree of insect infestation between the two areas.

Survival data were obtained after the first growing season in 1990. Survival, RCD, and height were also obtained after the 5th year (1994) and potentially dominant individual oak in the clearcut were identified. Competing vegetation density was recorded from three positions in each block during the 5th year measurement. Five artificially regenerated trees were excavated after the 5th growing season from both the shelterwood and clearcut areas to examine root development characteristics.

All artificially established individuals in both areas were measured prior to the 7th growing season. In the beginning of the 7th growing season (1997), the clearcut was released with a silvicide by establishing circles of 0.9 meter radius around each remaining dominant or co-dominant planted NRO seedlings. The shelterwood release was delayed until the 8th year prior to the spring flush. Prior to crown removal, all surviving NRO seedlings were conspicuously identified by flagging on the stems and tags attached at ground line to permit post harvest identification. The felling was such that whenever possible the tops were felled toward the outer boundary in an attempt to minimize damage to the surviving seedlings. In winter following shelterwood removal and completion of one growing season, individuals were placed into six groups as follows: 1. dead; 2. undamaged; 3. top one-third stem damaged; 4. top two-thirds stem damaged; 5. stem missing, sprouting from root collar; and 6. stem flat on ground, sprouting along entire length. The entire study was re-measured at this time and again after 3 years post release in January 2001.

RESULTS AND DISCUSSION

Basically, even with supposedly high quality seedlings, the shelterwood method proved to be unsatisfactory on this high quality site. Comparable results have been reported and have resulted in the misconception that artificial regeneration is not a viable option for NRO on those quality sites (Johnson 1993, McGee and Loftis 1986).

Performance of NRO seedlings in the clearcut, was very good even after a very shaky beginning. Indeed, several unanticipated factors significantly affected this experiment. The first, was a massive infestation of the 17 year locust (*Magicicada septendecim*) that severely damaged almost all 240 seedlings in the clearcut toward the end of the second growing season. However, only the artificially regenerated oak seedlings in the clearcut were affected while none of the oak seedlings in the shelterwood were attacked. No other species were damaged by this locust infestation. The second factor was the intense competition from untreated stumps and newly germinated seedlings of Carolina silverbell (*Halesia carolina*), red maple, and yellow poplar in the clearcut which continued unabated throughout the pre-release seven growing seasons. The final item, occurred one year post harvest when a leaf mining maggot (*Agromyza viridula*) attached the newly emerging leaf of only the NRO individuals in the clearcut. These maggots essentially eliminated a growth response during the first year post release. In contrast, the individuals in the shelterwood were free of disturbing factors.

Seedling Survival

Survival following the first season was 100 percent in both the clearcut and shelterwood understory plantings for all three FOLR groups of seedlings (table 1). The second year, locust damage was so extensive on seedlings in the clearcut that their long term survival appeared to be in doubt. Many stems were severely damaged over half to two-thirds of their height and lost much of the height advantage over newly germinated competitor species. Mortality rate accelerated during the third season but

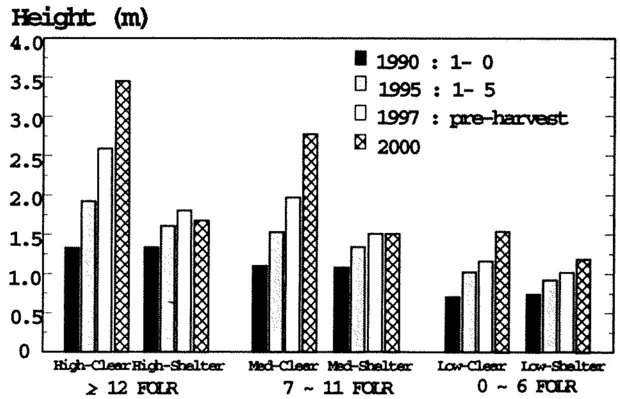

Figure 1–Percentage tree damage by grade in shelterwood planting after shelterwood removal.

stabilized by the initial re-measurement at age 5 (table 1). Seedling FOLR grouping really had no effect upon survival in the clearcut as survival was determined primarily by effects of the locust damage. Intense stump sprout competition also increased mortality in the clearcut site.

In the shelterwood most seedlings from all three FOLR groupings were intact at the 5th year measurement (table 1). A total of 20 trees had not survived in the shelterwood at age 5. Of these 20, 16 were low FOLR group, two in the medium group, and two in the high group. Survival remained relatively constant from the 5th to the 7th growing season for the high FOLR group but the individuals from the medium FOLR group were reduced in number to a greater extent than those from the clearcut (table 1). Survival did not change appreciably between the 5th and 7th year in the clearcut planting area. Release resulted in no accelerated mortality only for high group in the clearcut in the 11th year. Shelterwood removal resulted in considerable mortality in all three FOLR groupings. It also resulted in stem damage that is affecting the competitive potential of the surviving seedlings. The survival as well as the damage categories recognized after canopy removal are shown in figure 1. Less than one-third of the individual stems were undamaged and all others experienced considerable stem

Table 1—Northern red oak survival percentages by first-order lateral root groupings from clearcut and shelterwood plantings

	----------Clearcut-------			------Shelterwood-----		
Survival rate	High[a]	Medium	Low	High	Medium	Low
1st year	100	100	100	100	100	100
5th year	68	66	63	98	98	80
7th year	66	63	59	96	78	75
11th year	63	55	48	86	60	68

[a]High = 12; Medium = 7-11; Low = 0-6 first-order lateral root number.

damage that will in both the short and long-term affect their survival (figure 1).

Competitive Status of Natural Regeneration

Most of the naturally regenerated oak seedlings in the clearcut and shelterwood were less than 30 centimeter tall when the study was initiated and few were alive by age 7. Although we did not make an exhaustive survey, naturally regenerated NRO seedlings were rarely observed at year 7 or 11. We do not know whether this situation occurred due to limited mast production or insufficient sunlight for seedling development or both. In neither the shelterwood nor the clearcut, would natural northern red oak regeneration development have been sufficient for this species to be more than a minor or occasional component on this high-quality mesic site. Artificial regeneration in the clearcut has altered this possibility through at least age 11, and indicates artificial regeneration may play a role in maintaining a viable population of NRO on these high quality mesic sites.

Shelterwood

One of the objectives of a shelterwood is to limit sunlight that would encourage development of competing species yet provide sufficient sunlight for the NRO seedlings to become established. The original basal area reduction was effective through the 7th year, such that no low or mid-crown canopies had developed. However, even the high FOLR grade seedlings have not developed satisfactorily either before or post canopy removal. Height growth was minimal and RCD through the 5th year remained essentially unchanged from their initial caliper. The 7th year DBH measurements were unimpressive. The poor performance resulted in the decision to remove the shelterwood before the accelerating decline of individuals worsened. Prior to release, low FOLR group of seedlings was the smallest and they were spindly, although some of these above 1.0 meter might be considered "advanced" reproduction. (Loftis 1983, Sanders and Graney 1993). Characteristics of all shelterwood seedlings is that only a few leaves developed annually throughout the 7 years. Even on the largest seedling, seldom have we observed more than 20 to 30 leaves. Tip dieback has occurred several times on most of the seedlings but dieback to ground level was not observed prior to release. Partial dieback was not associated with any particular FOLR group. Poor vigor of the low and medium FOLR grades appeared to be responsible for mortality that occurred between the 5th and 7th year. The seedlings within a specific FOLR grouping were uniform in size and mortality did not appear to be related to their initial sizes.

Accounting for seedling response post release by FOLR grouping was difficult. This is because seedling damage did not appear to be related to their heights. Thus, when evaluating the shelterwood treatment, we combined all individuals, regardless of initial FOLR groupings for comparing initial seedling heights with 7th year pre-release and 3 years post harvest (table 2). All initial mean heights met or exceeded stem morphological conditions considered acceptable for advanced regeneration of NRO. Oak regeneration is not satisfactory in this shelterwood with a maximum growth response of only 60 centimeter

Table 2—Initial, seventh year pre-harvest and eleventh year post-harvest mean heights and stem condition of northern red oak 3 years after shelterwood removal

	Before Shelterwood Removal		Post-harvest
2000 Stem condition	Initial Ht 1990 (cm)	7th Year Ht 1997 (cm)	11th Year Ht 2000 (cm)
Dead	95	140	0
Undamaged	101	141	163
Top 1/3 stem damaged	105	139	115
Top 2/3 stem damaged	117	160	96
Stem missing - sprouting from root collar	108	145	84
Stem flat on ground - sprouting along length	141	193	103

for 11 years (table 2). These results are typical for NRO responses in a shelterwood and have contributed to artificial regeneration being a questionable recommendation.

Trees excavated from the shelterwood after year 5 showed that FOLR numbers had declined for each seedling examined. This was relatively unexpected. Underplanting or shelterwood regeneration assumptions are that the released seedlings or newly developed seedlings will develop a vigorous root system and be competitive when the stand is harvested even if top is damaged during canopy removal. It has been reported that unfavorable edaphic or environmental conditions such as low light intensity can result in a reduction in FOLR numbers and vigor with a preferential carbon allocation to the taproots at the expense of the lateral roots in NRO and white oak seedlings (Kormanik and others 1995, Sung and others 1998) as well as in loblolly pine trees (Sung and others 1996). Eventually, however, taproots begin to deteriorate and seedling mortality occurs. This unfavorable root deterioration was not observed on the individuals excavated from the clearcut area where photosynthetic active radiation was at least 1500 micromole/meter^2/second. The shelterwood had photosynthetic active radiation levels of less than 5 percent of this.

The pre-release seventh year mean height increases since shelterwood establishment for the high, medium, and low FOLR groups were 50, 40, and 30 centimeter, respectively (figure 2). The tallest seedlings were 280, 200, and 170 centimeter for each FOLR group, respectively. Three years post harvest showed the mean heights remained essentially the same or were reduced somewhat following shelterwood removal (figure 2). All seedlings under the shelterwood developed poorly and pre-release data indicate few seedlings were large enough to obtain DBH measurements. Three years post release DBH development was still unsatisfactory mirroring the lack of RCD growth for the first 5 years under the shelterwood (figure 3).

Clearcut

At age 5 when potential future dominant individuals were selected, the tallest individual from the high, medium, and low FOLR groupings were respectively 5.1, 4.6 and 2.4 meter. However at age seven and before release, only the selected individuals from the high and medium groups were still free-to-grow. Post release response was apparent with 6 to 8 meter trees being present by age 11 with mean heights of the high and medium FOLR grouping being 3.5 and 2.7 meter, respectively (figure 2). Post release DBH development, was impressive with almost a doubling in DBH over a 3 year period (figure 3). This response was in spite of the leaf maggot infestation during year one post release that seriously reduced leaf photosynthesis potential for that entire growing season.

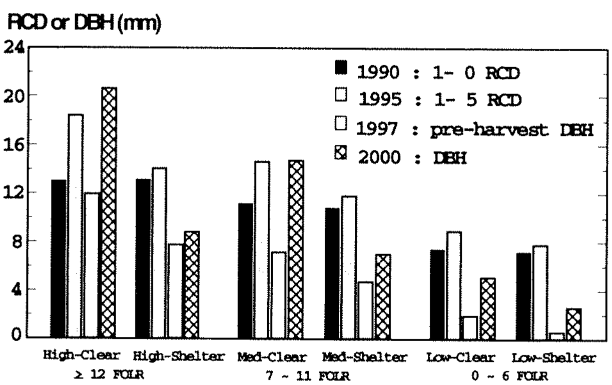

Figure 2–Height of northern red oak planted on clearcut site and under shelterwood.

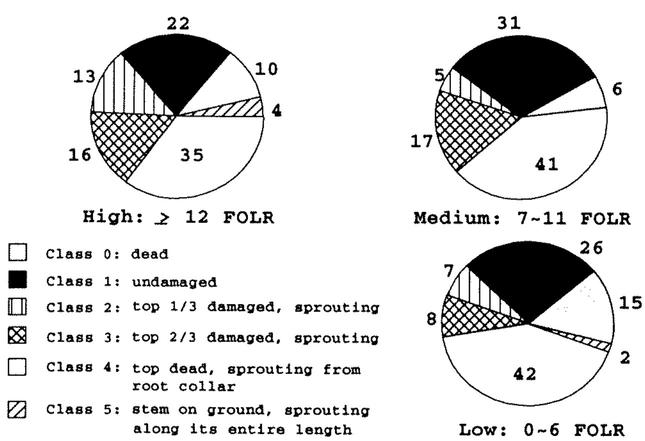

Figure 3–Diameter of northern red oak planted on clearcut site and under shelterwood.

Large differences were observed in all growth parameters among FOLR groups in the clearcut but survival as explained earlier was not related directly to FOLR groups or seedling sizes. All seedlings remained free-to-grow during their first year since stumps had not yet sprouted nor had the newly germinating competitors attained a competitive position. However, between years two and five, rapid growth of stump sprouts and development of new seedlings competitors resulted in steadily increasing competition. When the first re-measurements were made at year five, the artificially regenerated NRO seedlings were competing against 126,800 stems/hectare from 14 different deciduous hardwood species. However, the most severe competition was from stump sprouts of yellow poplar, red maple, and Carolina silverbell which each year became more critical as their rapidly developing crowns began to complete with the slower developing NRO crowns.

The competing vegetation was not re-inventoried prior to release but stem numbers did not appear to have declined much because of the absence of obvious mortality. At pre-release, age 7, competition of the dominant canopy level was primarily due to the rapidly growing stump sprouts. However, NRO individuals were still competing successfully against naturally regenerated seedling. These established small naturally regenerated seedlings did not respond immediately to clearcut and few of them produced more than 3 to 5 leaves either the first or second year following the clearcut and thus, as reported by others, did not benefit from it (Pope 1993).

Many of the large artificially regenerated seedlings remained free-to-grow or codominant until about the end of the 4th growing season unless they were planted immediately adjacent to stump sprouts. These large NRO seedlings that were at least 1 meter tall had a clear early advantage over competitors that began at ground level. During this first year the artificially regenerated oak benefitted from full sunlight and developed a root system required to compete with a wide range of competitors as the new stand developed.

Release at age 7 not only stimulated the NRO seedlings dramatically (figures 2, 3), but also had a comparable effect on the stump sprouts outside the 0.9 meter radius around the released individuals. Three years post release resulted in yellow poplar stump sprouts adjacent to the released individuals developing DBH's of 15 to 20 centimeter and obtaining heights of 6 to 10 meter. They are now, at age 11, clearly invading the NRO growing space. It is encouraging, however, that the potential dominant individuals selected at age 5, are still maintaining crown position with competitors of seedling origin but would benefit from further release to permit broader crown expansion.

CONCLUSION

After 11 years evidence is substantial that large NRO seedlings with adequate FOLR numbers are competitive and can be established on high quality mesic sites. Treatment of stumps prior to enrichment plantings or establishing mast producing areas will be required because even the largest and most competitive seedling cannot compete against stump sprouts on these excellent sites. In the absence of stump sprouts following an effective clearcut and site preparation, large NRO seedlings may not need release until ages 5 to 7 and, perhaps again at 10 to 12 years. Potential dominant trees that were selected at age 5, retained that status after release at age 7. Individual NRO oak seedlings with fewer than 4 FOLR were generally not competitive. Locust borer damage on them could not be ascertained from this study.

As of age 11, response from the shelterwood has not been satisfactory regardless of FOLR grouping. Neither height growth nor stem caliper have been acceptable compared to the clearcut response. The shelterwood site will be remeasured at 5 years post release. This will afford a comparison to the original clearcut at age 5 to determine to what degree the potential competition has developed since the shelterwood was removed. It appears unlikely, based on the ecology at these mesic sites, that any shelterwood type could be depended upon to establish NRO regeneration: too little sunlight and NRO will not grow or sufficient sunlight and the competitors will multiple rapidly. The question of what is too much overhead cover remains an open question and how to regulate competition to maintain NRO in a competitive position is difficult to ascertain. Certainly full sunlight is the best choice for NRO regeneration.

Neither shelterwood nor clearcutting in conjunction with the best most competitive NRO seedlings available will likely succeed in establishing this species on the desirable mesic sites without both mechanical and chemical control of competitors applied in a timely and effective schedule. Continued restriction in harvesting and chemical control of competitors may indeed contribute to NRO attaining the status of "California Condor" in the eastern deciduous forests as some have predicted (Kellison 1993).

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FIRST-YEAR SURVIVAL AND GROWTH OF BAREROOT AND CONTAINER WATER OAK AND WILLOW OAK SEEDLINGS GROWN AT DIFFERENT LEVELS OF MINERAL NUTRITION

Hans Williams and Matthew Stroupe[1]

Abstract—Bareroot and container water oak (*Quercus* nigra) and willow oak (*Quercus* phellos) seedlings were treated with 3 different levels of nitrogen (N) mineral fertilizer applied during the growing season in the nursery. Comparisons were made between species, N treatments, and stock-types for seedling morphology, first-year survival and height growth, and seedling water relations. Water oak seedlings were shorter, heavier, and more first-order lateral roots than the willow oak seedlings. The N fertilizer treatments did not have a statistically significant effect on seedling morphology. Bareroot seedlings were taller, had greater root-collar diameters, and were heavier than the container seedlings. The seedlings were hand-planted on an old pasture site located near Nacogdoches, TX. First-year survival was about 80 percent regardless of species, N treatment, or stock-type. Bareroot seedlings had less first-year height growth than container seedlings. Container seedlings fertilized at the highest N rate had greater stomatal conductance and transpiration rates early in the growing season than the container seedlings fertilized at the lowest rate.

INTRODUCTION

The reforestation of frequently flooded agricultural land with bottomland hardwood species has become an important activity in the Southeastern U.S. Federal programs like the Wetland Reserve Program (WRP) have promoted the reforestation efforts by providing financial support to landowners(Shepard 1995). A significant portion of the reforestation has occurred in the Lower Mississippi Alluvial Valley (LMAV). Compliance with the Clean Water Act and plantings initiated by organizations such as the The Nature Conservancy and Ducks Unlimited also contribute to the bottomland hardwood reforestation activity. Survival and early growth is often poor for these plantings because of frequent, long-term, flooding and herbaceous and woody plant competition. As a result, research continues to study ways to improve bottomland hardwood reforestation success (Allen 1990).

At locations where flooding is minimal, research results indicate that establishment with bareroot seedlings can be successful. Allen (1990) observed adequate bottomland hardwood oak stocking for five planted seedling stands (266 trees/ac.) and five direct seeded stands (293 trees/ ac.) about 6 years after establishment. Miwa (1995) observed first-year seedling survival greater than 70 percent for four bottomland hardwood species planted on hydric and non-hydric soils which no longer experience significant flooding. Five years after planting, seedling survival was still greater than 60 percent (Ozalp and others 1998). Stanturf and Kennedy (1996) observed survival exceeding 60 percent after 5 years for cherrybark oak (*Quercus pagoda)* seedlings planted in a floodplain clearcut.

The use of container-grown hardwood seedlings instead of bareroot seedlings may be a potential option for the reforestation of flood-prone sites. White and others(1970) presented the possible advantages of using container hardwood planting stock. Advantages that may be especially important to a wetland reforestation planner are the ability to extend the planting season and the higher survival usually observed on adverse sites. For example, container seedlings could be planted after the floodwaters recede in early summer. Bareroot seedlings, typically lifted from the nursery during the winter, must spend an extended period of time in cold storage prior to planting. Since hardwood seedlings are sometimes packed in bundles or bags that cannot be completely sealed, there is a risk of seedling desiccation during unplanned, long-term cold storage.

In this study, bareroot and container water oak and willow oak seedlings were treated at 3 different levels of nitrogen. The objectives of the research included studying the early survival and growth between bareroot and container seedlings. Also, the effects of altering N rates in the nursery were observed for seedling morphology and field survival and growth.

METHODS

The container seedlings were grown under a shadehouse located at Stephen F. Austin State University, Nacogdoches, TX. The shadehouse was covered with a fabric that allowed 50 percent of the incident light to reach the seedlings. Water oak and willow oak seed were purchased from a regional vendor. The seed were sown in March, 1996, in 164 cm^3 plastic cone container filled with a

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peat-perlite-vermiculite medium. Seedlings were grown at a density of 264 seedlings /m². The seedlings were irrigated as needed to prevent plant water stress.

The bareroot seedlings were grown at the Texas Forest Service Indian Mound Nursery, Alto, TX. The water oak and willow seed were collected from an orchard located near the nursery. The seed were sown in nursery beds in the Fall, 1995. During the 1996 growing season, the seedlings were irrigated with about 2 cm of water per week. The seedlings were top-pruned to a height of about 51 cm in July and August, 1996. Seedbed density at the end of the growing season was 86 seedlings/m² for water oak and 118 seedlings/m² for willow oak.

The fertilizer treatment involved increasing the nitrogen rate 2-times (2X) and 3-times (3X) the operational rate (1X). For the container seedings, a 15-30-15 (N-P_2O_5-K_2O) water soluble fertilizer was used. The 1X treatment, the operational rate, was equivalent to applying 34 kg N ha/yr. The fertilizer was applied over 10 applications during the 1996 growing season. The bareroot seedlings were fertilized with liquid ammonium nitrate (32-0-0). The 1X rate was equivalent to applying 18 kg N ha/yr. The fertilizer was applied over 5 applications during the 1996 growing season.

Prior to planting, ten seedlings were randomly sampled from each replication, stock-type, species and fertilizer treatment combination for biomass measurements. Each seedling was measured for height, root-collar diameter (RCD), number of first-order lateral roots (FOLR) greater than 1 mm in diameter, shoot oven-dry weight, and root oven-dry weight. The seedlings were hand-planted, using planting shovels, in January,1997. The planting site is at the Alazan Bayou Wildlife Management Area located about 11 km south of Nacogdoches, TX. The site was former pasture with soils from the Woden series(Typic Paleudalfs)and contains inclusions of soil from the Mantachie series (Aeric Fluvaquent) series.

Measurements after planting include first-year height growth and survival. Also, during the growing season following planting, leaf water potential, stomatal conductance, and transpiration was measured for container water oak and willow oak seedlings treated at the 1X and 3X N rates in late-June and late-August. Leaf water potential was measured with a plant pressure chamber. Stomatal conductance and transpiration was measured using a steady-state porometer. The measurements were conducted at mid-day (about 1:00 to 2:00 pm). The leaf water relation measurements were conducted on four seedlings from each replication, species, and N-rate treatment combination.

The study was designed as a randomized complete block split plot with 3 replications. The whole plots were the stock-types, the subplots were the species, and the sub-subplots were the N fertilizer rates. Differences between main effects and their interactions for the dependent variables measured are discussed as statistically significant at the 5 percent probability level.

Table 1—Mean morphological characteristics prior to planting of bareroot and container water oak and willow oak seedlings treated with three levels of nitrogen fertilizer

Treatment	Stem Height (cm)	Root-Collar Diameter (mm)	First-Order Lateral Roots (no.)	Shoot Weight (g)	Root Weight (g)
Stock-type					
Bareroot	65**	8.9*	10*	13.5*	14.3*
Container	38	5.5	5	1.8	3.0
Species					
WaterOak	50*	7.3	9*	8.7*	10.0*
Willow Oak	53	7.1	7	6.6	7.0
Nitrogen Rate[b]					
1X	49	7.1	8	7.6	9.0
2X	53	7.1	8	7.5	8.0
3X	52	7.4	8	7.8	9.0

[a] Means within a treatment followed by an asterisk are statistically different at the 5 percent probability level.
[b] The 1X N rate was 18 kg N ha/yr and 34 kg N ha/yr for bareroot seedlings and container seedlings, respectively.

RESULTS

Bareroot seedlings were taller, had larger RCD, were heavier and had greater number of FOLR than the container seedlings (table 1). Water oak seedlings were shorter than the willow oak seedlings, but had a greater number of FOLR. a. Means within a treatment followed by an asterisk are statistically different at the 5 percent probability level b. The 1X N rate was 18 kg N ha/yr and 34 kg N ha/yr for bareroot seedlings andcontainer seedlings, respectively Water oak seedlings were heavier than the willow oak seedlings. The N fertilizer treatment did not have a statistically significant effect on seedling morphology measured prior to planting. The statistically significant interactions between species and stock-types for seedling morphology were relatively small. Bareroot water oak seedlings were shorter than bareroot willow oak seedlings. Container water oak seedlings were taller than container willow oak seedlings. Bareroot seedlings fertilized at the higher N rates were shorter than the bareroot seedlings fertilized at the lowest N rate. Container seedlings were taller when fertilized at the higher N rates. Bareroot water oak seedlings had larger RCD than the bareroot willow oak seedlings, but the container seedlings of both species, had a similar RCD. Bareroot water oak seedlings had heavier stems than the bareroot willow oak seedlings. The container water oak seedlings had lighter stems than the container willow oak seedlings. Bareroot water oak seedlings had heavier roots than the bareroot willow oak seedlings. The container seedlings of both species had similar root weights. Bareroot willow oak seedlings had a

Table 2—Mean first-year survival, height growth and percent stem dieback for bareroot and container water oak and willow oak seedings treated in the nursery with 3 levels of nitrogen fertilizer

Treatment	Survival (Percent)	Stem Growth (cm)	Dieback (Percent)
Stock-type			
Bareroot	81	8*[a]	6.8
Container	83	27	1.1
Species			
WaterOak	81	15*	4.2
Willow Oak	82	20	3.7
Nitrogen Rate[b]			
1X	85	17	3.6
2X	81	19	4.1
3x	79	17	4.2

[a] Means within a treatment followed by an asterisk arestatistically different at the 5 percent probability level.
[b] The 1X N rate was 18 kg N ha/yr and 34 kg N ha/yr for bareroot seedlings and container seedlings,respectively.

Table 3—Mean mid-day stomatal conductance (g_w), transpiration (E), and leaf water potential (Y),for container water oak and willow oak seedlings treated in the nursery with 2 levels of nitrogen fertilizer. Seedlings measured during growing season after planting

Treatment	g_w (mmoles $m^{-2} s^{-1}$)	E (mmoles $m^{-2} s^{-1}$)	Y (MPa)
	June 23-27, 1997		
Species			
Water Oak	343.0	7.84	-1.6
Willow Oak	264.2	6.2	-1.7
Nitrogen Rate			
1 X	258.9*[a]	5.97*	-1.6
3 X	343.7	8.07	-1.7
	August 25-28, 1997		
Species			
WaterOak	434.5	12.20	-1.8
WillowOak	431.4	12.41	-2.2
Nitrogen Rate[b]			
1 X	402.6	11.73	-2.1
3 X	463.3	12.89	-2.0

[a] For each sample period, means within a treatmentfollowed by an asterisk are statistically different atthe 5 percent probability level.
[b] The 1X N rate was 18 kg N ha/yr and 34 kgN ha/yr bareroot seedlings and container seedlings, respectively.

lower number of FOLR than the bareroot water oak seedlings. Container seedlings of both species have similar numbers of FOLR. Water oak seedlings fertilized at the higher N rates had greater numbers of FOLR than water oaks fertilized at the lowest N rate. Willow oak seedlings fertilized at the lowest N rate had higher numbers of FOLR than the willow oak seedlings fertilized with the higher N rates.

First-year survival after planting was about 80 percent or greater regardless of stock-type, species or N-rate treatments (table 2). Container seedlings had greater first-year shoot growth than the bareroot seedlings. Willow oak seedlings had greater shoot growth than the water oak seedlings. The N fertilizer treatment did not affect first-year survival and shoot growth. Bareroot willow oak seedlings had greater amounts of shoot growth than the bareroot water oak seedlings. The container seedlings of both species had similar amounts of shoot growth. Bareroot seedlings fertilized at the higher N rates had greater shoot growth than the bareroot seedlings fertilized at the lowest N rate. First-year height growth was less for container seedlings fertilized at the highest N rates.

The difference in mid-day stomatal conductance, transpiration, and leaf water potential between container water oak and willow oak seedlings was not statistically significant when measured in late-June and late-August following planting (table 3). The container seedlings fertilized at the highest N rate had statistically greater rates of stomatal conductance and transpiration when measured in late-June. Differences between N-rate treatments were not statistically significant when measured in late-August.

CONCLUSIONS

The careful seedling handling and planting and the adequate growing conditions may partially explain the good first-year survival for all treatment combinations. While the seedlings were planted in a location with significant herbaceous and woody plant competition, the 1997 growing season was characterized by above average rainfall. In August alone, over 30 cm of rain occurred in Nacogdoches, TX. Bareroot hardwood seedlings require careful handling, especially to protect the root systems. However, when the right species are matched to the site and proper handling and planting procedures are followed, good early establishment of bareroot seedlings should be expected (Kennedy 1993). The greater first-year height growth observed for the container seedlings may be a response to the reduced handling and planting stress when compared to bareroot seedlings (White and others 1970). Williams and Craft (1998) observed similar first-year results for bareroot and container Nuttall oak (*Quercus texana*) seedlings planted on a hydric soil in the LMAV.

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CHERRYBARK OAKS FROM PERFORATED CONTAINERS PLANTED AS BAREROOTS WITH OPEN-GROWN OAK BAREROOTS

Kirk D. Howell[1]

Abstract—Large Cherrybark oak (Q. *pagoda* Raf.) grown for two years (1997 and 1998) were hoedad planted in bottomlands near Columbia, South Carolina. Successful oak plantations exist from planted bareroot cherrybark oak seedlings with heights below 50 centimeters, but costly efforts were often employed to ensure success. To overcome competing vegetation, seedlings greater than 1 meter are essential, but the roots of large oak seedlings present obstacles to planting. The one-liter, perforated container was designed to promote fine, feeder roots to penetrate outside of the container, and to restrict woody root formation at the soil-container interface. After two nursery growing seasons, there were no significant differences in survival, but yield favored conventional bareroot seedlings of 100 per square meter. Field survival of containerized seedlings after two years were significantly greater than bareroot seedlings, compensating for the higher cost of containerized seedlings. Seedlings from containerized stock of 100 per square meter also showed the greatest significant yield by year two.

INTRODUCTION

With increased demand for high quality oak products and potential legislation to restrict clearing of natural forests (Kellison 1993), it may not be enough to simply mimic nature = s processes in artificial oak regeneration, but to improve on them. Producing higher yield on less land with fewer starting costs is a prudent goal for the land manager, regardless of whether the land is publicly or privately owned.

Much research has been conducted to show the importance of oak seedlings having a bulky root system, and hence several first-order lateral roots (FOLR) (Ruehle and Kormanik 1986), which give rise to second-order laterals roots, and to fine, fibrous roots. For greatest stem size potential, it is preferable to have greater than 8 FOLR along the distal tap (Kormanik et al. 1994), with FOLR diameters above 1mm (Thompson and Schultz 1994). Otherwise, seedlings are labeled by some researchers as Agenetic trash@. Unfortunately, after the planting process, root pruning (i.e., tailoring the seedling's root system to fit the planting hole) compromises many of these gains realized in the nursery.

Oak plantation success (i.e., an efficient operation) hinges on 1) high yield and 2) low initial costs. Poor cost efficiency involves one or both factors being deficient. In a study established in 1994 (Howell and Harrington 2002), undersized cherrybark oak (Q. *pagoda* Raf.) seedlings, grown three months in a greenhouse, survived and grew quite well, but not without the aid of high-priced fencing to protect them from browse. Moving away from protective shelters, a preferable option might be found with larger seedlings planted in open-field conditions.

The optimum size that would ensure plantation success at the lowest possible cost is debatable.
Ground-line diameter may be the single most useful morphological measure of seedling quality (Johnson and Cline 1991) — ensuring field survival and promoting rapid growth (Mexal and South 1991); moreover, diameter is a good indicator of root mass (Coutts 1987). A competitive oak seedling should have a ground-line diameter above 10 millimeters (Pope 1993). Moreover, stem height above 1.5 meters is considered adequate to overcome competing vegetation and deer browse (Hannah 1987).

The perforated container (U.S. #6,173.531), patented in January 2001, is designed to restrict and train root growth. The patented hole perforations are to be substantially 1.5 millimeters, the midpoint between woody and feeder-root range, > 2 and < 1 millimeters, respectively (Lyford 1980). Upon inserting these containers into the ground, fine and fibrous root growth is encouraged, and the taproot should extend to the bottom of the container, where it follows the water pathway out of the container into the surrounding seedbed. With these large containers, the soil can be removed at the nursery for economic reasons, and thus bareroot seedling transport and planting are facilitated, hence the term Acontainerized-bareroot@. Therefore, the objectives of plantability and ease of transport should be satisfied, but what is more important is that this method may offer a more positive yield forecast.

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MATERIALS AND METHODS

Cherrybark oak seeds were sown (February 1997) as conventional bareroot or inside perforated containers in a partially shaded nursery in Auburn, GA. Two densities of 64 and 100 seeds per square meter were also tested. A third factor of perforation size (1 versus 1.5 millimeter holes) was tested for containers, and for conventional bareroot, the factor of trimming versus nontrimming was tested at planting. Thus, a randomized block design was employed with eight treatments across three blocks in the nursery, and 20 seeds sown per treatment per block. A completely randomized design was installed where nine stems were selected from each treatment, and replications were planted in designated positions in the field.

Due to the shaded conditions, portable greenhouses and lighting were used to provide a 2-month head start on the 1997 season. Seedlings emerged by early March, and by April 1, 1997, all growth devices were removed. Another aid to promote high-density growth was with lateral branch pruning. This operation was performed for six months (late April-late September) for two years. Seedlings were fertilized with (20N-20P-20K) daily during the active growing season. Seedlings were not undercut, and after lifting, were immediately transported to the planting site. At planting, trimming was performed on designated bareroot seedlings and all seedlings were planted at a 3.66 by 3.66-meter spacing.

Diameter, height, and survival are yield factors expressed in the equation: $Y_t = Avg(B*r_t^2*h_t)/2*S_t$; where at year t: Y_t = yield (cubic decimeters), r_t = radius (decimeters), h_t = height (decimeters), and S_t = percent survival. Nursery yield, two years from sowing (November 1998), was expressed in terms of stems per 1000. Plantation yield, two years from planting (December 2000), was expressed in terms of 750 stems per hectare.

Our research was not empirical, so cost information was adopted from a firm of undisclosed identity. The nursery involved 20 hectare with a workable area of 7,500 square meters per hectare (25 percent non-workable roads and buffer areas). With about 67 percent germination in our study, there was an effective production of 6.4 and 10 million stems from densities of 64 and 100 stems per square meter, respectively. All costs were influenced by capacity, and were thus included in pricing, whether fixed or variable. Salaries, land, dues, insurance, etc. are some items to be included which did not vary with treatment. Other costs included were the purchase and handling of containers, portable greenhouses, and labor required to package, store, and transport seedlings. When pricing, 30 percent profit was added. Thus, the price from the nursery became the seedling cost for each treatment in the field. Seedling price and planting costs were also variable in this study. Land and site preparation costs were not included in this paper. Costs were compounded with time (t) as follows: $C_t = EC * (1+i)^t$; where: C_t = total cost ($); EC = the sum of all costs ($); i = interest (8 percent).

Yield to cost ratios (E_c) provide cost efficiency indices. The equation is given as: $E_c = C_t/Y_t$; where: E_c = cost efficiency ($ per cubic decimeters), C_t = total cost ($ per 1000 or $ per hectare), and Y_t = yield in terms of yield (cubic decimeters per 1000 or per hectare).

RESULTS AND DISCUSSION

In the nursery, we realized near 65 percent representation (emergence and survival), due to poor germination, and there with no significant differences (" 0.05) among treatments. Thus, effective density was less than that which was sown. After two years in the field (table 1), containerized bareroot had significant survival (about 78 percent) over conventional bareroot (about 49 percent). Nursery diameter, height, and yield favored conventional bareroot of density 100, and year-2 field diameter, height, and yield favored containerized-bareroot of density 100. As to why density 100 seedlings were larger than those of density 64 may be partly explained by the effective lower density after germination. However, since both treatment densities were reduced equally, the lowest density (64 seedlings per square meter) should have remained low and should have still supported the larger stems. Lateral branch pruning, which encourages mutual training, may have also had some impact on these results. Root alteration (Alt) showed no significant impact on yield or cost with containerized bareroot. However, the conventional bareroot, trimmed, 64 treatment was significantly greater than the rest in yield by year two.

Fixed costs (FC) ranged from 50 to 55 percent of the total costs of producing conventional bareroots. However, with containerization fixed costs ranged from 39 to 45 percent of the total, because about $30 per 1000 was needed to purchase containers (C), and an additional $55 per 1000 to embed and hand-sow the containers (SC). Mechanization of sowing conventional bareroot with two workers ($20 per hour) and a tractor drove sowing costs (SC) down to about 48 cents per 1000, plus or minus 5 percent for differences in density. Laborers involved in hand sowing, and other fieldwork, earn $10 per hour. If embedding containers could be mechanized, the higher wage and initial investments in machinery would over the long run lower the cost of the container-sowing operation. On the other hand, a $7,000 savings from not using the tractor when hand-sowing containers resulted in a minimal adjustment of $1 to $2 per 1000 (shown with FC). Some could argue that this justifies hand sowing using cheap labor.

Lateral branch pruning (table 2) was a cost factor unaffected by density ($62 per 1000), but the greatest cost benefit was realized by the fostering of increased basal diameter growth at the higher density. Lateral branch pruning (BP) also affected transport and packaging (TPK). Weight of a load to equal 13,620 grams (30 pounds) was utilized to determine the cost of transport and packaging. Since soil was removed from the containers at the nursery, and transport and packaging dealt with bareroot only, then the costs involved in transport was virtually the same for each treatment ($3.8 to $4.5 per 1000).

Table 1—Percent survival (Srv), diameter (Dia: mm), height (Hgt: cm), yield (Yld: cubic decimeters per 1000 for the nursery or per hectare in the field), and cost efficiency (Eff: dollars per cubic decimeter) at year-2 nursery (N), year-2 field (2), transport and planting costs (TP(0): dollars per hectare), and year-2 field cost (Cst(2): dollars per hectare) for each treatment of root form (containerized bareroot (container) and conventional bareroot (bareroot)), density (64 or 100 stems per square meter), and root alteration (Alt: 1.5 versus 1.0 millimeter holes in containers, or trimmed (Trim) versus not trimmed (Xtrm) applied to bareroots in the field). Reported significance (S) at ? = 0.05 level. Notation: no difference (N); Forms differ (F); Densities differ (D); and the form-density interaction (FD).

Form:	Container				Bareroot				
Dens:	*64*		*100*		*64*		*100*		
Alt:	1.0	1.5	1.0	1.5	Trim	Xtrm	Trim	Xtrm	-S-
Srv(N):	63	77	72	58	63	63	65	65	N
Srv(2):	73	92	73	73	51	40	48	55	F
Dia(N):	8.9	9.9	9.1	8.6	8.8	8.8	10.2	10.2	FD
Dia(2):	14.7	13.9	16.8	18.1	14.3	12.9	13.2	11.3	FD
Hgt(N):	101	116	112	112	105	105	124	124	FD
Hgt(2):	131	140	180	171	148	124	125	124	FD
Yld(N):	39	48	37	41	39	39	57	57	FD
Yld(2):	81	94	127	149	81	34	43	30	FD
Eff(N):	11.5	9.4	9.5	8.6	9.4	9.4	4.6	4.6	FD
Eff(2):	7.4	6.1	4.0	3.3	6.2	15.8	8.8	13.5	FD
TP(N):	115	89	122	108	98	139	89	123	
Cst(2):	599	576	506	493	502	538	377	406	

The variable costs were responsible for adding an approximate $100 to containerized treatment over the conventional bareroot treatment. All costs (variable and fixed) were affected by density, since recompense involves seedling quantities rather than seedling qualities. If products were priced according to aspects of quality, pricing would be in terms of dollars per weight or volume. The cost of nursery land ($6.4 and $4.2 per 1000 for densities of 64 and 100, respectively) was spread over 30 years, and was an insignificant charge as compared to the total cost of operations.

Table 2— An itemized cost list (dollars per 1000) involving fixed costs (FC) in the nursery (wages and salaries, operations, utilities, and anything which is not specified separately). Other variables include costs of: land (LC), sowing (SC), lifting (Lft), loading and packaging (TPK), containers (C), fertilization and supplies (F), small portable greenhouses and lighting (GL) and branch pruning (BP). Year-2 total cost is also listed (Cst).

Form:	-Container-		-Bareroot-		Form:	-Container-		-Bareroot-	
Dens:	-64-	-100-	-64-	-100-	Dens:	-64-	-100-	-64-	-100-
FC:	202	129	204	130	LC	6.4	4.2	6.4	4.2
SC:	53	58	.46	.50	Lft:	12.3	11.5	7.6	9.3
TPK:	3.8	4.5	4.2	3.8	C:	30	30	0	0
GL:	78	50	78	50	F:	3	2	3	2
Cst:	450	351	366	262	BP:	62	62	62	62

In the field (table 2), nursery cost with 30 percent profit made up the price of seedlings. Some states may require tax, but our state did not. Transport and planting (TP) involved an average charge of $150 per 1000 for large seedlings, as compared to a charge of $35 per 1000 for planting small, bareroot seedlings in the 1995 study (Howell and Harrington 2002). It is intuitive that larger seedlings will demand higher seedling prices and will require greater costs to plant them. Nevertheless, one worker planting 100 saplings per hour is well within the realm of a large-scale planting production rate. The cost of trimming bareroot seedlings was offset by the cost of carrying and planting untrimmed seedlings.

Cost efficient nursery benchmarks (table 1) were set by the conventional bareroot of density 100, because it possessed the lowest costs and also had the highest yield. The $4.6 per cubic decimeter of this study was about 47 times as low as the best treatment of the 1995 study ($215 per cubic decimeters). After two years in the field, the containerized bareroot of density 100 was optimum, where high yield overcame the relatively higher costs of production, and it was the low field survival that hurt the conventional bareroot. The $3.8 per cubic decimeter value of this study was about three times below that of the best treatment ($12.4 per cubic decimeters) of the 1995 study. There were some protection mechanisms utilized in the 1995 study, which were not needed in this study. The only other costs that could be realistically added to this study are the cost of land and site preparation. These marginal costs are minimal compared to the other costs, and would not greatly dilute the cost efficiency results of this study.

CONCLUSION

Containerization effectively restricts the root system to parameters conducive to high-volume planting, while preserving the fibrous root important for nutrient uptake in the field. The perforated container, used in this study, brought into one operation the benefits of both containerized and bareroot seedling culture, where perforated holes permitted only fine roots, those less than 2 millimeters in diameter (Hendrick and Pregitzer 1993), to penetrate the container interface into an extended rooting environment. While the general rule holds true for all forest species, this fine-woody root transition range between 1 and 2 millimeters (Lyford 1980) is subject to vary somewhat among species.

Neither cost inputs nor the yield output should be under emphasized in nursery or plantation levels. The long-term payoff (i.e., the return on the invested dollar) will depend upon: 1) stand yield, highlighting representation (emergence and survival); 2) individual stem yield, promoting high volume growth; and 3) the cost to produce, establish, and sustain the crop. Benchmarks in cost, yield, and their combined efficiency should be set, and will thus encourage the comparisons of operations over space (from region to region) and time (from generation to generation).

The cost benchmark at the nursery level was set in this study by the conventional bareroot treatment, of density 100, but the small, unfertilized treatment from the 1995 study held the best mark between the two studies (Howell and Harrington 2002). When looking at variable costs only, the same treatment from the 1995 study would logically remain lowest in seedling cost, and the cost of transport and planting. However, the cost of spending several thousand dollars per hectare to fence and protect undersized seedlings actually negates any perceived advantage in an applicable sense. The field cost efficiency benchmarks of this study were manifested; even though higher priced saplings were utilized, which involved greater storage, transport and establishment costs. However, the bonus is that they were planted in a clearcut area with a high-volume planting tool, and without the aid of expensive shelters or fences for protection.

While nursery yield was best for the conventional bareroot, density 100 treatment, after two years in the field, the containerized, density 100 treatment set a second-year benchmark in this study. Second-year nursery yield in our study was 20 times that of the best treatment from the 1995 study, because our seedlings had a morphological age perhaps closer to what would be classified as fifth-year growth under natural conditions. Five-year morphological sizes are required for saplings to have a fighting chance to survive in indigenous sites where pioneer conifers and hardwoods possess faster growth rates (Clatterbuck 1987), especially for upland oaks on upland sites (McGee 1975; Loftis 1983). The oak paradox seems to be epitomized more with northern red oak than it is with cherrybark oak.

The container, 100 treatment showed the best cost efficiency in our study, and now offers a milestone with which to engage future findings. Undoubtedly, the cost efficiency benchmark set in this study will soon be superceded by innovative measures, which reduce costs or increase performance. Some of these measures may be found in: 1) growing larger seedlings at higher densities; 2) increasing seedling representation through improvements in germination and survival methods; and 3) facilitating branch pruning and/or root initiation by way of chemical or hormonal application. Once oak plantation success can be guaranteed on clearcuts of high site quality, morphologically superior oaks may be interplanted with low-cost, 1-0 pines for training purposes. As of now, however, pines are viewed as major oak competitors.

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GROWTH AND DEVELOPMENT OF FIRST-YEAR NURSERY-GROWN WHITE OAK SEEDLINGS OF INDIVIDUAL MOTHER TREES

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Abstract—White oak (*Quercus alba* L.) acorns from individual mother trees at Arrowhead Seed Orchard (ASO, Milledgeville, GA), Beech Creek Seed Orchard (BSO, Murphy, NC), and Savannah River Site (SRS, Aiken,SC) were sown in December 1999 at Whitehall Experiment Forest Nursery (Athens, GA). All 6 mother trees from BSO were grafted. By early April, germination exceeded 80percent for all but six families. Five of these six families were from BSO. Seedlings that emerged after mid-April generally were much smaller in size than those emerging earlier. More than 60 percent of seedlings from each seed source group had fewer than mean first-order lateral root (FOLR) number. Buds for the first flushes started swelling near the end of April for most seedlings. Time span from current bud swelling to next bud swelling in most seedlings was approximately 33 days for all flushes. Regardless of seed sources, elongation of the third, fourth, and fifth flushes occurred mainly between 4 and 12 days post bud break (dpbb) with most active elongation occurring approximately 10 dpbb. About 89, 55, and 9 percent of ASO and SRS seedlings had three, four, and five flushes, respectively. Only 60, 15, and 2 percent of BSO seedlings had three, four, and five flushes. Seedlings with first flush length shorter than 5 centimeter generally had lower values in growth parameters including height, root collar diameter, flush number, and FOLR number. Based on germination rate and first flush length, it may be possible to assess progeny quality of given mother trees as early as mid-May. Progeny from grafted mother trees performed poorly in nursery as compared to progeny from other groups based on all parameters except for diameter.

INTRODUCTION

There have been two *Quercus* regeneration practices used to maintain a significant oak component in new stands following a harvest. One practice depends on obtaining advanced oak regeneration by shelterwood or selection harvesting the current stands. Although this may be successful on lower quality upland sites (Sanders 1971, Lortis 1983), it may not be successful on high quality mesic sites due to the presence of fast growing, competing woody species that will generally occupy the site once the final canopy is removed (Loftis 1990, Hodges and Gardiner 1993, Lorimer 1993). The other practice, artificial oak regeneration, involves planting high quality 1-0 nursery stocks on clearcut sites as advocated by Kormanik and others (1997,1998,2000). This practice takes only the top 50 percent of 1-0 oak seedlings grown under a specific hardwood nursery protocol developed by Kormanik and others (1995). Seedlings are graded by their height, root collar diameter (RCD), and number of first-order lateral roots (FOLR) that are greater than 1 mm in diameter. It has been proven with loblolly pine (Kormanik and others 1990) and various oak species including white oak (Kormanik and others 1997, 2000) that FOLR number is highly heritable and a good indicator of seedling quality in nursery and outplanted performance in field.

Here we investigated the growth and development of 1-0 white oak seedlings from different mother trees from different states. The primary interest was to identify and quantify any early indicator of seedling quality that might be used with progeny from future mother tree selections.

MATERIALS AND METHODS

Open pollinated white oak (*Quercus alba* L.) acorns from individual mother trees in Arrowhead Seed Orchard (ASO, Milledgeville, GA), Beech Creek Seed Orchard (BSO, Murphy, NC) and Savannah River Site forest stands (SRS, Aiken, SC) were sown at a density of 54 to 57 per meter^2 in December 1999 at Whitehall Experiment Forest Nursery (Athens, GA). Seedlings were grown using the oak nursery protocol of Kormanik and others (1994). There were 25, 6, and 15 half-sib families from ASO, BSO, and SRS, respectively. All 6 mother trees from BSO were grafted. Four ASO, six BSO, and 14 SRS families were planted in a randomized block design with two blocks each consisting of 130 acorns per family. The other families were planted in an identical manner but with only 65 acorns per family per block. Germination percent was assessed as shoot emergence on March 23 and April 5, 2000. Numbers of seedlings with swelling first flush bud that was at least 3 millimeter long or elongating first flush were recorded for

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Table 1—Germination and flush development of all white oak seedlings from individual mother trees at Arrowhead Seed Orchard (ASO), Beech Creek Seed Orchard (BSO), and Savannah River Site forest stands (SRS)

	ASO[a]	BSO	SRS
Acorn FW[b] (g)	4.6±1.2	4.3±1.1	4.3±1.1
Mar 23 Germ (pct)	85±8.9	60±29.0	87±7.4
Apr 5 Germ (pct)	90±8.0	62±30.0	92±4.9
Apr 25 1st Fl[c] (pct)	28±10.9	20±10.5	18±12.5
May 29 2nd Fl (pct)	55±9.2	27±8.1	37±17.3

[a] In December 1999, acorns from 25 ASO, 6 BSO, and 15 SRS mother trees were sown.
[b] Mean acorn fresh weigh (± sd) were obtained by weighing the entire family before sowing.
[c] Seedlings with swelling flush bud or elongating flush were considered to have initial flush development.

each family on April 25. Seedlings with swelling second flush bud or elongating second flush were counted for all families on May 29. All seedlings were lifted in late January 2001. Height, root collar diameter (RCD), and FOLR number were recorded for all seedlings of each of the 12 ASO, 6 BSO, and 15 SRS families. Thirteen ASO families with 65 acorns per family per block were not evaluated for these growth parameters.

In mid-April, 2000 we established the "All Flush Development Sub-study" that intensively followed 10 ASO, five BSO, and five SRS families. These families were part of those assessed for height, RCD, and FOLR number at lifting. For families with 65 acorn per replication every fifth seedlings were tagged for observation. For those families with 130 acorns per replication, every tenth seedling was tagged. This resulted in 13 seedlings per replication in each of the 20 families. Thus, a total of 520 seedlings were assessed for flush development two to three times a week throughout the growing season. The date of bud break as determined by the first appearance of a flush leaf, flush length, and leaf length were recorded.

On June 12, the "Detailed Flush Development Sub-study" was initiated on an additional 144 seedlings with swelling third flush buds. These seedlings were labeled and followed daily for flush elongation and leaf expansion. Development of the fourth and fifth flushes were followed every other day. This sub-study consisted of 68 seedlings from 18 ASO families, 9 seedlings from five BSO families, and 67 seedlings from 13 SRS families. Flush length was modeled on an individual seedling basis with the logistic equation defined as:

$$FLUSH = \frac{a}{(1 + e^{b + c\,DAY})}$$

where FLUSH = flush length (cm), DAY = days post bud break, and a, b, c = parameters of the logistic function. Nonlinear regression was used to estimate the parameters using PROC NLIN (SAS Institute Inc. 1989). The instantaneous rate of flush growth at a given day was obtained by determining the slope of the specific logistic

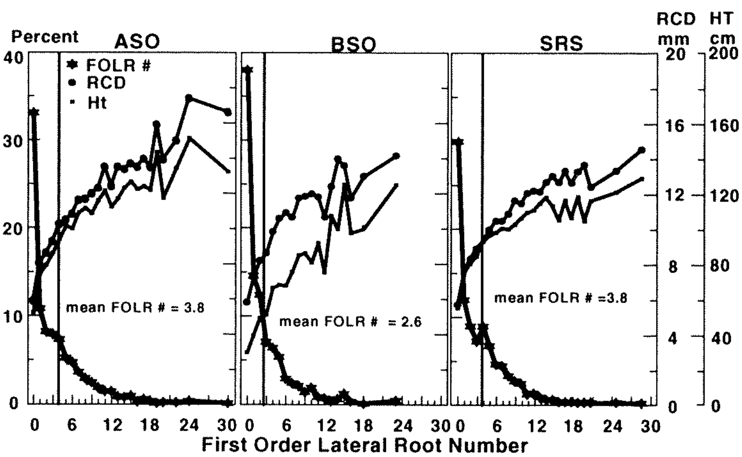

Figure 1—Frequency distribution of first-order lateral root (FOLR) number of 1-0 white oak seedlings with height and root collar diameter in each FOLR group. Acorns were from 12, 6, and 15 individual mother trees at Arrowhead Seed Orchard, Beech Creek Seed Orchard, and Savannah River Site forest stands, respectively.

Table 2—Comparisons between late emerging (after April 15, 2000) and normal emerging white oak seedlings from individual mother trees at Arrowhead Seed Orchard (ASO), Beech Creek Seed Orchard (BSO), and Savannah River Site forest stands (SRS)

Emergence time	Seed source	Germination Pct	Height cm	RCD mm	FOLR #
Normal[a]	ASO[b]	90.0	82±35.0	9.0±3.3	3.8±4.9
Late	ASO	0.5	52±28.0	5.6±2.2	1.4±2.2
Normal	BSO	72.0	49±28.3	8.1±2.7	2.7±3.6
Late	BSO	7.2	33±16.8	6.1±2.0	0.9±1.7
Normal	SRS	86.0	82±30.6	8.6±2.8	3.9±4.5
Late	SRS	2.4	48±29.8	5.1±2.5	1.0±2.3

[a] Seedlings germinated before April 15.
[b] Twelve ASO, 5 BSO, and 15 SRS families were assessed. Family NAWO-23 was not included because it only had 5 percent germination.

equation evaluated at that day. This was found by differentiation with respect to DAY, yielding

$$\text{SLOPE} = \frac{-a\,c\,e^{b+c\,\text{DAY}}}{(1+e^{b+c\,\text{Day}})^2}$$

and then substituting the appropriate day in this equation. The inflection point of the logistic function is where the instantaneous rate of flush growth reaches its maximum and begins to slow down. It is found by setting the second derivative equal to zero and solving for DAY, which yields Inflection Day = -b/a

RESULTS AND DISCUSSION

Main Study

Germination percentages were similar between ASO and SRS families with BSO having 25 percent less germination in March and April (table 1). By April 5, all but six families had more than 80 percent germination (data not shown). Families ASO-1, NAWO-23, SAWO-38, SAWO-28, NAWO-29, and NAWO-28 had 55, 5, 48, 73, 78, and 79 percent germination, respectively. The latter five families were from the Beech Creek Seed Orchard. No correlation existed between acorn weight and germination percent of individual families. Of these seed sources, more ASO seedlings started forming the first flush on April 25 and the second flush on May 29 than seedlings of the other two groups. More SRS seedlings had the second flush than BSO on May 29 (table 1).

When seedlings were pooled within each seed source and stratified based on their FOLR numbers, all three seed sources exhibited a reversed J distribution (figure 1). This relationship was also exhibited on an individual family basis (data not shown). Similar FOLR distributions have been reported for loblolly pine (Kormanik and others 1990) and various oak species including white oak (Kormanik and others 1997). Sixty-seven percent of ASO, 65 percent of SRS, and 70 percent of BSO seedlings had fewer than their respective mean FOLR number (figure 1). These values were comparable to the white oak results observed by Kormanik and others (1997). In the present study, 33, 30, and 38 percent of ASO, SRS, and BSO seedlings, respectively, had zero FOLR. Correlation coefficients between FOLR number and RCD were 0.75, 0.74, and 0.72 for ASO, BSO, and SRS seedlings. Correlation coefficients between FOLR number and height were 0.64, 0.69, and 0.55 for ASO, BSO, and SRS seedlings. Mean RCD were similar among three seed sources whereas BSO seedlings were 40 percent shorter than ASO or SRS seedlings (figure 1, table 2). There was a higher percent of late emerging BSO seedlings than SRS seedlings (table 2). Only a few ASO seedlings emerged after April 15. All the late emerging seedlings were smaller in size and had fewer FOLR than the normal seedlings (table 2).

Family SRS-596 had 85 percent germination on April 5 and about 35percent of these seedlings were albino, that is, their leaves had very low levels of chlorophyll. These seedlings eventually died. Furthermore, compared to the SRS group means, the green SRS-596 seedlings were smaller in size with 47 centimeter height and 6.8 millimeter RCD, but had 4.2 FOLR which is comparable to SRS group mean. Family KYWO-31 is the only grafted tree that had 91 percent germination in April. Still, mean height for this family was only 55 centimeter. Results from previous studies of acorns collected from grafted mother trees at BSO, including some of the same families in this study, showed low germination percent and short seedling size (Kormanik and others 1997). Reasons for poor germination and shorter stem for progenies from most grafted mother trees in Beech Creek Seed Orchard are unclear. This study indicated that based on germination percent, morphology, and growth parameters, ASO-1, SRS-596, and all BSO mother trees produce poor quality progeny.

Detailed Flush Development Sub-study

Figure 2 shows the daily growth of the third flush of an ASO-16 seedling with leaf length (long axis) expansion for the fourth leaf from the bottom of the flush. Most of the 144

Table 3—Growth and developmental parameter means (± sd) of 520 white oak seedlings from individual mother trees at Arrowhead Seed Orchard (ASO), Beech Creek Seed Orchard (BSO), and Savannah River Site forest stands (SRS)

	ASO	BSO	SRS
		General Growth Parameters	
Height (cm)	80±32.8	50±29.6	76±33.6
Root collar diameter (mm)	9.4±2.9	8.3±2.6	8.0±2.9
First-order lat root number	3.9±5.1	2.6±3.8	4.3±6.0
		From Bud Swelling to Bud Swelling (d)	
1st flush to 2nd flush	32.5±5.2	32.4±3.9	32.8±6.1
2nd flush to 3rd flush	32.2±4.1	35.9±6.0	33.2±3.9
3rd flush to 4th flush	33.0±4.6	35.8±5.4	33.0±3.5
4th flush to 5th flush	32.4±3.0	32.0±1.4	33.0±5.5
		Flush Length (cm)	
Epicotyl	10.3±2.1	8.0±2.3	9.1±2.0
1st flush[a]	7.9±3.2	4.6±2.4	7.1±2.5
2nd flush	16.7±5.6	14.9±6.1	14.5±5.2
3rd flush	26.2±6.4	27.0±10.0	25.2±7.1
4th flush	36.2±9.1	38.0±17.7	35.2±9.9
5th flush	31.0±9.8	26.2±4.7	27.6±8.8
		Seedling Percentage (pct)	
1st flush	99	100	100
2nd flush	98	89	98
3rd flush	87	60	88
4th flush	53	16	57
5th flush	9	2	9

[a] Mean flush length was derived from sum of flush length divided by number of seedlings with that given flush, instead of total seedling number. Therefore, sum of epicotyl length and all five flush lengths is greater than measure height.

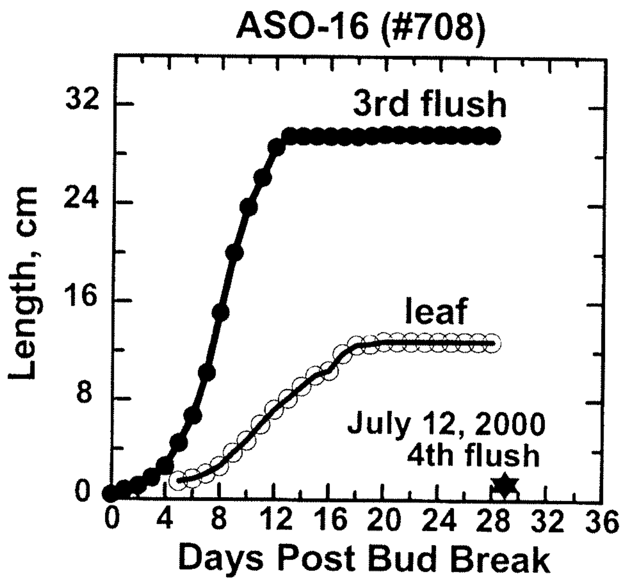

Figure 2—Daily elongation of the third flush and leaf length extension of the fourth leaf from the bottom of the third flush in a white oak seedling from family ASO-16.

seedlings selected for the Detailed Flush Development Sub-study had similar temporal patterns for flush elongation and leaf expansion curves. Generally, flush elongation was linear between 4 and 13 dpbb (figure 2). Leaf expansion lagged several days behind active flush elongation. There seemed to be a span of one week between leaf maturation and appearance of the next flush bud for most seedlings.

For the Detailed Flush Development Sub-study, only the third, fourth, fifth flush growth curves of ASO seedlings were presented in figure 3. Similar curves were observed with SRS seedlings (data not shown). Inflection points for the third, fourth, and fifth flushes of ASO seedlings were 9.7, 12.4, and 10.9 dpbb. Slopes, (i.e., elongation rates, centimeter/day), at the inflection point for the third, fourth, and fifth flush were 3.9, 3.7, and 4.6 (figure 3). Inflection point (dpbb) and its slope for the third, fourth, and fifth flushes of SRS seedlings were as follows: 9.6 and 3.4, 11.1 and 3.5, and 10.1 and 4.3, respectively. The third flush growth curve of BSO seedlings had the inflection point at 10.9 dpbb with a slope of 4.5.

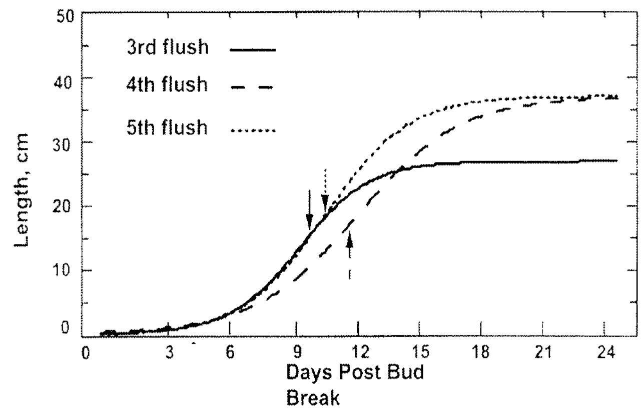

Figure 3—Logistic curves for third, fourth, and fifth flush development of the same white oak seedlings from Arrowhead Seed Orchard. The inflection points were indicated with arrows. Sixty-eight seedlings were included for the third flush development. Of these seedlings, 63 had the fourth flush and 37 produced the fifth

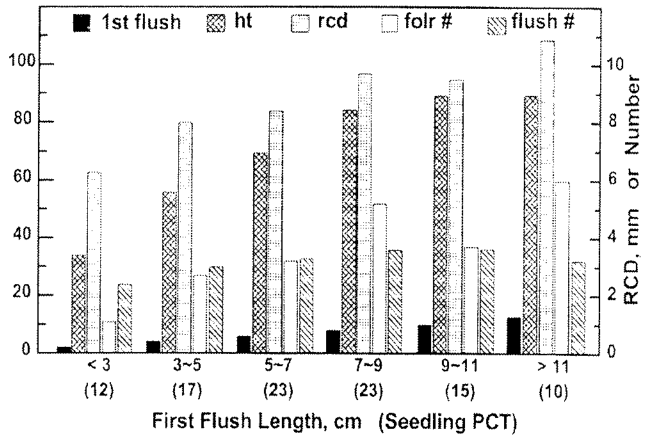

Figure 4—Growth parameter means of 520 1-0 white oak seedlings grouped by the length of their first flushes. Acorns were from 10, 5, and 5 individual mother trees at Arrowhead Seed Orchard, Beech Creek Seed Orchard, and Savannah River Site forest stands, respectively. Values in parentheses were centages of seedlings in each group.

All Flush Development Sub-study

The 520 seedlings selected for the All Flush Development Sub-study had similar height, RCD, and FOLR number to their corresponding group in the Main Study (table 3 versus figure 1). Seedlings of ASO and SRS were also comparable in all growth parameters including individual flush length and flush number (table 3). More than half of ASO and SRS seedlings had four flushes as compared to only 16 percent for BSO seedlings. Furthermore, BSO seedlings had the shortest first flushes.

First flush buds began to swell in late April. Mean julian days for swelling of the first flush buds were 118 ± 5.0, 120 ± 6.8, and 121 ± 7.7 for ASO, BSO, and SRS, respectively. A span of 33 days existed from the swelling of a flush bud to the swelling of the subsequent flush bud for all flushes of ASO and SRS seedlings (table 3). However, BSO seedlings had a span of 36 days for second to third and for third to fourth flush bud swelling. For some seedlings, when a bud appeared much later than the average bud to bud span of 33 to 36 days, these buds usually remained tight for the rest of the growing season. For all seedlings, each flush was longer than its previous flush except for flush five which was shorter than the fourth (table 3). This might be related to a shortening photoperiod during the fifth flush development in September.

It has been reported that heritability estimates are in the range of 0.55 to 0.92 with small standard errors for various oak species (Kormanik and others 1997) and loblolly pine (Kormanik and others 1990). Seedlings with many FOLR are competitors in the nursery and perform well after outplanting (Kormanik and others 1998, this proceedings). Thus, in our effort to artificially regenerate oak stands on high quality mesic sites, three criteria have been used to grade 1-0 seedlings at lifting (Kormanik and others 1997,1998,2000). They are $60 centimeter height, $7 millimeter RCD, and $ 5 FOLR for white oak (Kormanik and others 2000). The mean FOLR was suggested to be the most important seedling selection criterion (Kormanik and others, 1997, 1998, 2000). In this study, mean FOLR for ASO and SRS was about 4 (table 2). Mean FOLR for BSO was 2.6. Seedlings which met at least two of the three criteria, namely $ mean FOLR, $ 8 millimeter RCD, and $ 70 centimeter height were outplanted on various National Forests in Georgia, South Carolina, North Carolina, and Tennessee in February 2001 for seed orchard establishment. Field performance of these seedlings will be followed over time.

Figure 4 presents the 520 seedlings in the All Flush Development Sub-study based on their first flush length. It is evident that seedlings with first flushes shorter than 5 centimeter did not meet two of our three nursery grading standards. About forty percent of the seedlings were evaluated as low quality stocks (figure 4). Since most seedlings finished their first flush elongation by mid-May, it might be feasible to assess the quality of first year nursery-grown seedlings by mid-May. All seedlings in this sub-study were transplanted into nearby nursery beds at Whitehall Experiment Forest. Their performance also will be monitored.

Combining the data of germination percent, seedling morphology (such as albino leaf), and first flush length, one should be able to identify competitive progeny before June. For example, most seedlings from BSO had first flush lengths shorter than 5 centimeter, mean heights less than 70 centimeter, and germination rates less than 80 percent (tables 1, 3). Acorns from these grafted mother trees should not be collected in the future for artificial oak regeneration. Our future study will test the following two hypotheses: that heritability estimates for first flush length of 1-0 nursery-grown oak seedlings are similar to those for FOLR number and that there are high correlations between these two parameters. In addition to FOLR number, first flush length might be a good indicator of seedling competitiveness and performance in the nursery and field.

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HAND PLANTING VERSUS MACHINE PLANTING OF BOTTOMLAND RED OAKS ON FORMER AGRICULTURAL FIELDS IN LOUISIANA'S MISSISSIPPI ALLUVIAL PLAIN: SIXTH-YEAR RESULTS

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Abstract—Interest in restoring bottomland hardwoods on abandoned agricultural fields has gained considerably over the past 15 years, due primarily to federal cost-share programs such as the Conservation Reserve Program and the Wetlands Reserve Program. While a variety of artificial regeneration techniques are available to afforest these lands, none have met with consistently successful results, especially in the Mississippi Alluvial Plain. Therefore, a study was initiated to compare a variety of regeneration techniques for afforesting previously farmed bottomland hardwood sites. In this paper we report the results from hand planted versus machine planted 1-0 bare-root bottomland red oak seedlings. Four sites in the MAP in Louisiana were planted with either 1 or 2 species in a randomized complete block design. Sites and species planted included Bayou Macon Wildlife Management Area [WMA; Nuttall oak (*Quercus nuttallii* Palmer) and willow oak (*Q. phellos* L.)], Lake Ophelia National Wildlife Refuge (NWR; Nuttall oak), Ouachita WMA (willow oak), and the Tensas NWR [Nuttall oak and water oak (*Q. nigra* L.)]. Results after 6 growing seasons indicated little difference in density, survival, planting success, and stocking between planting methods. Densities ranged from 280 Nuttall oak seedlings per acre machine planted at the Tensas NWR to 67 willow oak seedlings per acre machine planted at the Bayou Macon WMA. Nuttall oak also tended to have higher survival (81 percent) compared to willow oak (56 percent) and water oak (38 percent). When volunteer oak and ash were included, all site-species-planting method combinations met the minimum criteria for successful afforestation, but all combinations failed to meet minimum stocking levels necessary for quality sawtimber production.

INTRODUCTION

Interest in restoring bottomland hardwood forests on former agricultural land (afforestation) has increased considerably over the past 15 years (Allen and Kennedy 1989, Schweitzer and Stanturf 1997, Gardiner and others In press). This interest on private lands has coincided with the advent of several government cost-share programs that provide financial assistance to establish trees on these lands; chief among these programs are the Conservation Reserve Program and the Wetlands Reserve Program (WRP) (Cubbage and Gunter 1987, Kennedy 1990). Interest in restoring bottomland hardwood forests on public lands is due to the recognized importance of these forests for their various wildlife habitat functions and values (Richardson 1994). Nearly 100,000 acres of former agricultural land had been afforested in the Mississippi Alluvial Plain (MAP) of Arkansas, Louisiana, and Mississippi by 1995 with potentially another 110,000 acres by 2005 (Stanturf and others 1998).

Common afforestation techniques involve either planting seedlings or sowing seed, particularly oak (*Quercus* spp.) acorns (Stanturf and others 1998, Gardiner and others In press). Much debate has existed concerning which technique is superior to ensure greatest success of afforestation efforts. Sowing seed is often touted as an easier and cheaper afforestation technique than planting seedlings (Bullard and others 1992). Direct seeding also has a larger planting window compared to planting seedlings (Johnson 1983). Likewise, advantages to planting seedlings include an easier evaluation of the planting operation, and potentially greater survival and growth (Ozalp and others 1998). Because past experience with direct seeding has not been as successful as desired, several state agencies require that seedlings be used to qualify for government cost-share programs (Mr. Larry Nance, Arkansas Forestry Commission, Little Rock, AR, pers. comm.).

The question that arises once a decision has been made to plant seedlings is whether to hand plant or machine plant. A common recommendation is to machine plant if possible because machine planting can substantially speed up the planting job in soils other than heavy clays (Allen and Kennedy 1989). It is commonly cited that one person can hand plant between 600-800 hardwood seedlings per day if conditions are good (Allen and Kennedy 1989, Kennedy 1990, Kennedy 1993) while an experienced crew of two or three people can machine plant 4,000-10,000 hardwood seedlings per day (Kennedy 1990, Kennedy 1993, Stanturf and others 1998). Many of the comments regarding hand planting or machine planting oak seedlings on bottomland sites are based on personal

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observations or results with planting pine (*Pinus* spp.) species on upland sites (Ezell 1987, Long 1991). Little work has focused on direct comparisons of hand versus machine planting hardwood seedlings on bottomland sites (Russell 1997, Russell and others 1998). The objective of this research was to compare hand versus machine planting of several bottomland red oak species on former agricultural fields at different locations in the MAP in Louisiana. Sixth-year post-planting results are presented.

MATERIALS AND METHODS

Locations

The study was conducted on abandoned agricultural fields at 4 locations in Louisiana's MAP. Though none of these sites receive direct flooding from a major river system (i.e., the Mississippi River or the Red River), each site floods from localized weather events and backwater of minor rivers and bayous. Each site is described separately below.

The Bayou Macon Wildlife Management Area (WMA) is located in East Carroll Parish in northeast LA. The study site is located about 2.5 miles east of Bayou Macon, north of East Carroll Parish Highway 3330. The forest was cleared in the 1960s and planted to agricultural crops. The area was purchased in 1991 by the Louisiana Department of Wildlife and Fisheries (LDWF) and converted into a state wildlife management area. Soils are Sharkey clay (very-fine, smectitic, thermic Chromic Epiaquerts) based on a detailed survey by National Resource Conservation Service (NRCS) personnel (NRCS soil survey field notes for each site are on file with the School of Forestry, Wildlife, and Fisheries (SFWF), Louisiana State University (LSU), Baton Rouge, LA) with an estimated site index, based age 50 years, of 90 for Nuttall oak (*Q. nuttallii* Palmer) (Baker and Broadfoot 1979).

The Lake Ophelia National Wildlife Refuge (NWR) is located in Avoyelles Parish in east-central LA. The study site is located 2-4 miles, depending on replication, from the Red River and is protected from river flooding by the main-line levee system. The forest on this site was cleared in the 1960s and planted to agricultural crops. The area was purchased by the U.S. Department of Interior Fish and Wildlife Service (FWS) and converted to a federal national wildlife refuge. Soils are of the Tensas/Sharkey complex (Tensas silty clay - fine, smectitic, thermic Aeric Epiaqualfs) with the former soil occupying ridges and the latter occupying lower elevation areas. Nuttall oak site index was estimated to be 90 (Baker and Broadfoot 1979).

The Ouachita WMA is located in Ouachita Parish in northeast LA. The study site is located about six miles southeast of Monroe, LA south of Highway 15 near the Bayou LaFourche River. The forest on this site was cleared in the 1960s or 1970s and planted to agricultural crops. The area was purchased in 1984 by the LDWF and converted to a state wildlife management area. Soils are a mixture of Portland silty clay (very-fine, mixed, nonacid, thermic Vertic Haplaquepts) and Hebert silt loam (fine-silty, mixed, thermic Aeric Ochraqualfs). Inspection of the soil prior to study establishment indicated that the Herbert silt loam is shallow (8-9 inches) and turns powdery when dry. This soil is underlain by the Portland clay. Nuttall oak site index was estimated to be 85 (Baker and Broadfoot 1979).

The Tensas NWR is located in Madison Parish in northeast LA. The study site is located about seven miles south of Interstate 20, three miles northeast of the refuge headquarters, and about one mile east of the Tensas River. The forest on this site was cleared in 1970s and planted to agricultural crops. The area was eventually purchased by the FWS and converted to a federal wildlife refuge. Soils are of the Tensas/Sharkey complex as previously described. Nuttall oak site index was estimated to be 90 (Baker and Broadfoot 1979).

Planting Methods/Design

As part of a larger afforestation study, 14 combinations of direct seeding and planting seedling treatments were utilized (see McCoy and others (2002) in this conference proceedings for a complete description of the direct seeding treatments). Two of these 14 combinations involved hand planting and machine planting of 1-0 red oak seedlings. These two treatments are the focus of this paper.

At each study site, 1-acre square treatment plots (209 feet on each side) were laid out for each treatment. Each plot was surrounded by a 33-foot buffer zone to allow equipment to turn around without affecting neighboring plots. For the seedling planting treatments, each plot was tilled in the Fall 1993 prior to planting. Bare-root, 1-0 planting stock purchased from the LA Department of Agriculture and Forestry's Columbia Nursery was used at each site. Three red oak species were utilized in the study: Nuttall oak and willow oak (*Q. phellos* L.) at the Bayou Macon WMA, Nuttall oak at the Lake Ophelia NWR, willow oak at the Ouachita WMA, and Nuttall oak and water oak (*Q. nigra* L.) at the Tensas NWR. Nuttall oak was the primary species used due to proven success at various afforestation sites throughout the MAP. The other species were chosen based on site conditions, and to compare with Nuttall oak if space at the site permitted. Planting was done in January or February, 1994 at each site. The target spacing was 12 feet by 12 feet or 302 seedlings for the 1-acre plot. The general design was to plant 17-18 seedlings in each of 17 rows (289-306 seedlings per acre). Hand planting was conducted using dibble bars. Machine planting was done using a lift planter on the state wildlife management areas which made furrows 6-10 inches deep (averaged 8 inches) depending on soil moisture conditions. Machine planting on the national wildlife refuges was done using a FESCO planter. While a general plan for planting was developed, final planting operations were conducting by officials associated with each wildlife management area or national wildlife refuge. The purpose for this decentralized control was to make operations as practical and applicable as possible, but problems did occur. Weather conditions at several sites resulted in machine planting being conducted under wet conditions. Such conditions, combined with the heavy clay soils, resulted in clay clogging the planting machine and some seedlings not being planted optimally. Furthermore, the target spacing was not always obtained due to mechanical problems with the machine planter, site conditions, and the way planted seedlings were counted.

Measurements and Analyses

Measurements for each of the 4 study sites were conducted during November 1999, 6 growing seasons after planting. Four 0.025-acre (0.01-ha) circular plots were established 20 meters diagonally from each of the four corners for each square 1-acre treatment plot. In each measurement plot, all tree seedlings and saplings (including natural reproduction) were tallied in 1 of 6 size classes by species: 0-30 cm tall, 30-50 cm, 50-100 cm, 100-140 cm, 140 cm - 2.5 cm dbh, and > 2.5 cm dbh. These size classes correspond to a standard sampling protocol used by the USGS Wetlands Research Center in Lafayette, Louisiana. A pvc stake flag was placed at each measurement plot center and electronic measuring devices were used to circle the plot while tallying trees by size class.

Analyses involved determining density, survival, and success of oak species planted in each plot, and stocking values of desired species (both planted oaks and volunteer oaks and green ash). All plot-level counts were converted to per-acre values and averaged across each plot to obtained density (number of stems per acre) by size class. Size classes were then summed to obtain total number of stems by plot. Survival was calculated by dividing the density counts by the actual number of seedlings planted, while planting success was calculated by dividing the density counts by the target number of seedlings planted (302 per acre). Stocking values were determined by assigning point values to each size class following Johnson's (1980) bottomland hardwood regeneration evaluation model as updated by Hart and others (1995). Size-class counts were done using the metric system of units while the bottomland hardwood regeneration evaluation model used English units. Therefore, the following points were assigned to each size class for oak and ash, respectively: (1) 0-30 cm; 0.5 points for both, (2) 30-50 cm and 50-100 cm; 2 and 6 points, and (3) 100-140 cm, 140 cm - 2.5 cm dbh, and >2.5 cm dbh; 3 and 6 points. This point assignment closely follows those developed by Hart and others (1995) using size classes based in English units. Each plot was considered stocked if it contained ≥ 12.0 points for a 0.01-acre plot. Density counts were adjusted from the 0.01-ha measurement plot to a 0.01-acre plot. Analysis-of-variance using a randomized complete block design with 3 replications per site and planted species was used to compare hand planting and machine planting treatments by site. Blocking was done by elevation of the site, i.e., ridges, flats, etc. Variables analyzed included density, survival, planting success, points, and stocking. Analyses were conducted using PC-SAS and an alpha level of 0.05 was used to determine significant differences (SAS 1985).

RESULTS AND DISCUSSION

Density

Seedling density, 6 growing seasons after planting ranged from 280 per acre for machine-planted Nuttall oak on the Tensas NWR site to 67 per acre for machine-planted willow oak on the Bayou Macon WMA site (table 1). Only one significant difference was found between planting methods with hand-planted willow oak having a greater density than machine-planted willow oak (table 1). In general, Nuttall oak plantings resulted in greater densities than the other oak species, especially when planted on the same site.

WRP guidelines state that for a site to be considered successfully afforested 125 stems per acre (either planted or natural) must be present 3 years after planting. Seventy-five percent of the site-species-treatment combinations met this minimum although these densities represent 6 years after planting instead of 3 years. Of interest is that all the Nuttall oak site-planting method combinations met this criteria, while only 3 of the 6 other site-species-planting method combinations met this criteria. When volunteer oaks and green ash were included in density calculations, all sites met the 125 stems per acre WRP minimum criteria for successful afforestation.

Survival

Survival 6 years after planting ranged from 97 percent for machine planted Nuttall oak on the Tensas NWR to 26 percent for machine planted willow oak on the Bayou Macon WMA (table 1). As with density, Nuttall oak tended to perform better than either willow oak or water oak when planted on similar sites. This was especially true for the Tensas NWR site. Nuttall oak averaged 92 percent survival across treatments while water oak averaged only 38 percent.

Various factors may have influenced these survival values. First, the sampling protocol involved 4 subplots for each treatment plot. Standard error values associated with each survival value ranged from 3 for hand-planted willow oak to 16 for hand-planted Nuttall oak, both on the Bayou Macon WMA. Sampling error must be taken into account when interpreting these survival values (table 1). Second, state wildlife management areas and federal wildlife refuges were planted by personnel associated with each agency. On several sites, the number of seedlings planted was calculated by subtracting the number of seedlings left in nursery package bags from an assumed total number of seedlings in the bag prior to planting. This assumption was not always correct as seedling counts in several bags was less than indicated on the bag label. A third factor involved seedling quality. Planting records indicated that several seedlings were simply too small (less than 18 inches in height and 0.5-0.75 inches in root-collar diameter). Small seedlings planted in abandoned agricultural fields are at a disadvantage to competing vegetation due to less stored food reserves in the root system. Another seedling quality issue was mixing of species. It was noted in the records that water oak seedlings were mixed with the willow oak seedlings at the nursery; therefore, some water oak was planted in willow oak treatment plots. Water oak, being less flood tolerant than willow oak, would be expected to have higher mortality rates on several of the sites used in this study.

Success

Regeneration success evaluates the current density of seedlings and saplings compared to the target planting rate set prior to the planting operation. If the target rate is met during the planting operation then survival and success are the same measures. But rarely does operational planting meet target rates; therefore, regeneration success may be a better criteria to evaluate the longer-term results of afforestation efforts. Regeneration success closely followed survival

Table 1—Sixth year density, survival, regeneration succuss, and stocking by site, species, and planting method for bottmland red oaks planted on abandoned agricultural fields in Louisiana's Mississippi Alluvial Plain Numbers in parentheses represent one standard error[a]

Site	Species	Planting Treatment	Initial Density	1999 Density	Survival	Success	Points	Stocked Plots	WRP Success
			stems/ac	stems/ac	percent	percent	unitless	percent	
Bayou Macon WMA	Nuttall oak	hand	300	226	75	75	13.0	42	yes
			(2)	(47)	(16)	(16)	(2.7)		
		machine	286	250	87	83	10.4	25	yes
			(10)	(9)	(4)	(3)	(0.9)		
	willow oak	hand	281	148	53	49	14.7	50	yes
			(2)	(9)	(3)	(3)	(2.8)		
		machine	269	67	26	22	7.4	17	no
			(11)	(27)	(11)	(9)	(4.0)		
Lake Ophelia NWR	Nuttall oak	hand	330a	169	51	56	4.7	0	yes
			(0)	(29)	(9)	(10)	(0.6)		
		machine	306b	273	89	90	10.4	25	yes
			(0)	(20)	(7)	(7)	(1.3)		
Ouachita WMA	willow oak	hand	297	233a	78	77a	6.5a	0	yes
			(1)	(21)	(7)	(7)	(0.6)		
		machine	276	185b	68	61b	5.2b	0	yes
			(21)	(17)	(8)	(6)	(0.6)		
Tensas NWR	Nuttall oak	hand	289	253	88	84	11.2	33	yes
			(0)	(36)	(12)	(12)	(2.2)		
		machine	289	280	97	93	10.8	33	yes
			(0)	(38)	(13)	(12)	(1.1)		
	water oak	hand	289	101	35	34	7.1	17	no
			(0)	(16)	(5)	(5)	(2.9)		
		machine	289	121	42	40	6.9	17	no
			(0)	(23)	(8)	(8)	(1.4)		

[a]Numbers followed by different letters within a site, species, planting combination are significantly different at p = 0.05

trends in this study (table 1). Initial planting density usually did not reach the target density of 302 seedlings per acre (table 1). On several sites, initial density was as low as 90 percent of the target planting density. Variable initial density resulted from difficult planting conditions for machine planting on several sites and simply running out of seedlings. Regeneration success though was not well correlated with the initial density. The highest initial density, 330 hand-planted Nuttall oak on the Lake Ophelia NWR, had only 56 percent success 6 years later. Obviously, other factors are involved in the success of artificial regeneration efforts than simply how many seedlings are initially planted.

Stocking

Johnson (1980) initially developed a regeneration evaluation system for bottomland hardwoods. Points were assigned to regeneration present before a harvest (advance regeneration) based on their size and to trees based on their stump sprouting potential. Using 0.01-acre circular plots, points would be summed for desirable species until a minimum threshold of 12 points was reached. Once 12 points was obtained then the plot was considered fully stocked with desirable species. This regeneration evaluation system was develop for natural regeneration of pre-existing bottomland hardwood stands with a management objective of growing high-quality sawlogs. The system was later modified by Hart and others (1985) and Belli and others (1999) based on additional research into the regeneration dynamics of bottomland red oaks and green ash following harvesting. While developed for pre-existing stands, this regeneration evaluation system may be applied to afforested situations because we believe that stocking principles, such as points by size class and distribution of stocked plots, are similar regardless of stand initiation conditions.

The average number of points scored by treatment ranged from 14.7 for the hand-planted willow oak on the Bayou Macon WMA to 5.2 for machine-planted willow oak on the Ouachita WMA (table 1). The latter site was the only one in which a significant difference in the number of points occurred with hand-planted plots having more points than machine-planted plots. In general, sites planted with Nuttall oak scored better than sites planted with either willow oak or water oak. Only 2 of the > 12 site-species-planting method combinations averaged points 12, the Bayou Macon WMA hand-planted Nuttall oak and willow oak treatments. Plots on this site tended to have a significant component of natural green ash that was distributed from an adjacent stand. The remaining 10 combinations scored less than the minimum necessary to be considered fully stocked although four of these combinations average > 10 points.

Hart and others (1995) warned not to average points across plots because an average score may indicate that regeneration may be adequate when in reality only a few plots had considerably greater than average points that skewed the average score higher. Hart and others (1995) recommended a more appropriate application of the regeneration evaluation system would be to determine the percentage of plots that met the minimum threshold of 12 points. Johnson and Deen (1993) recommended that 60-70 percent of the plots needed to meet the 12-point minimum for the site to be considered adequately stocked. The number of plots meeting this criteria ranged from 0-50 percent across the site-species-treatment combinations (12 regeneration plots for each site-species-planting method combination for a total of 144 plots; table 1); therefore, none of the areas that were planted, regardless of planting method, would be considered successfully regenerated after 6 growing seasons if the primarily objective was quality sawtimber production.

CONCLUSIONS

Little difference was found in the density, survival, and planting success of bottomland red oak seedlings and stocking of oak and ash seedlings and saplings between hand planted and machine planted treatments 6 years after planting. But, according to notes taken during planting operations (notes on file at the SFWF, LSU) and discussions with personnel who conducted the planting operations, machine planting conditions were less than ideal. Officials with the LDWF indicated that when planting operations are under ideal conditions, i.e., soils are neither too wet or too dry, they consistently get 5-10 percent greater survival for machine planting compared to hand planting (Kenny Ribbeck and Buddy Duprey, LDWF, Baton Rouge and Pineville, LA, respectively). Others have also found greater survival of machine planted bottomland red oak species when compared to hand planting (Russell and others 1998). Results from this study indicate that various considerations, such as site conditions and costs, are necessary in determining whether to machine plant or hand plant bottomland red oak seedlings.

A second observation from this study was the success or failure of the treatments depended on the afforestation objective(s). Although 6-year results were presented, all site-species-planting method combinations met the minimum density required by the WRP program (keeping in mind that WRP success is based on third-year post-planting observations). Success was obtained with only the planted oaks and volunteer oaks and green ash. Other species were found in the measurement plots (see McCoy and others (2002) in this conference proceedings), further solidifying WRP success. Concurrently, all site-species-planting method combinations failed to meet stocking criteria for quality sawlog production, even when volunteer oak and ash were included in stocking calculations. The important point is that specific management objective(s) should be developed before afforestation activities commence.

A third observation from this study was that Nuttall oak consistently outperformed willow oak and water oak. On heavy clay soils, such as those found in the MAP, Nuttall oak is often the preferred species, due to its greater flood tolerance, on these potentially harsh sites. Results from this study confirm other observations and studies that Nuttall oak is a preferred species for afforesting abandoned agricultural fields with clay soils in the MAP (Stanturf and others 1998). It is very important that only quality hardwood seedlings are purchased from nurseries, that species are properly matched to site conditions, and that constant oversight is conducted during planting operations. Attention to these factors will increase the success of any afforestation effort on bottomland sites (Gardiner and others (In press), Stanturf and others 1998).

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SUPPLEMENTAL PLANTING OF EARLY SUCCESSIONAL TREE SPECIES DURING BOTTOMLAND HARDWOOD AFFORESTATION

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Abstract—Reforestation of former bottomland hardwood forests that have been cleared for agriculture (i.e., afforestation) has historically emphasized planting heavy-seeded oaks (*Quercus* spp.) and pecans (*Carya* spp.). These species are slow to develop vertical forest structure. However, vertical forest structure is key to colonization of afforested sites by forest birds. Although early-successional tree species often enhance vertical structure, few of these species invade afforested sites that are distant from seed sources. Furthermore, many land mangers are reluctant to establish and maintain stands of fast-growing plantation trees. Therefore, on 40 afforested bottomland sites, we supplemented heavy-seeded seedlings with 8 patches of fast-growing trees: 4 patches of 12 eastern cottonwood (*Populus deltoides*) stem cuttings and 4 patches of 12 American sycamore (*Platanus occidentalis*) seedlings. To enhance survival and growth, tree patches were subjected to 4 weed control treatments: (1) physical weed barriers, (2) chemical herbicide, (3) both physical and chemical weed control, or (4) no weed control. Overall, first-year survival of cottonwood and sycamore was 25 percent and 47 percent, respectively. Second-year survival of extant trees was 52 percent for cottonwood and 77 percent for sycamore. Physical weed barriers increased survival of cottonwoods to 30 percent versus 18 percent survival with no weed control. Similarly, sycamore survival was increased from 49 percent without weed control to 64 percent with physical weed barriers. Chemical weed control adversely impacted sycamore and reduced survival to 35 percent. Tree heights did not differ between species or among weed control treatments. Girdling of trees by deer often destroyed saplings. Thus, little increase in vertical structure was detected between growing seasons. Application of fertilizer and protection via tree shelters did not improve survival or vertical development of sycamore or cottonwood.

INTRODUCTION

Throughout the world, and specifically within the southeastern United States, forested wetlands have been lost (Turner and others 1981, Noss and others 1995). Within the Mississippi River floodplain, over 7 million ha of bottomland hardwood forest have been lost (Knutson and Klaas 1998, Twedt and Loesch 1999). Most of this land is now used for agriculture, but continued intermittent flooding and unfavorable agricultural prices often result in marginal profitability. The uncertainty of financial return and concurrent environmental concerns associated with the loss of forested wetlands have prompted conservation initiatives to reverse the loss of forested wetlands throughout the United States and particularly within the Mississippi Valley (Lower Mississippi Valley Joint Venture Management Board 1990, Creasman and others 1992, Mueller and others 2000). Spurred by both economic considerations and increased awareness of the ecological and societal benefits afforded by forested wetlands, >180,000 ha currently in agricultural production are anticipated to be afforested within the Mississippi Alluvial Valley by 2005 (Stanturf and others 1998).

The ecology of bottomland hardwood forests reveals succinct successional progressions influenced by soil and hydrology (Hodges 1997) and high species diversity (Allen 1997). Despite the temporal and taxonomic diversity within bottomland hardwood forests, afforestation of bottomland sites on public lands and on private lands, through forest easements, has historically emphasized planting seedlings of heavy-seeded hardwood species such as oaks (*Quercus* spp.) and pecans (*Carya* spp.) or sowing seeds (acorns) of these species. Indeed, oaks and sweet pecan (*Carya illinoensis*) have been planted on nearly 80 percent of all afforestation in the Mississippi Alluvial Valley (King and Keeland 1999).

Planting predominantly oaks in bottomland restorations is intended to provide a "jump-start" for succession toward seasonally wet oak-hardwood forests (Kennedy and Nowacki 1997) that have oaks as dominant canopy species. This species selection has been justified because of high value of subsequent timber harvest, potential mast production for wildlife food, and an assumption that light-seeded species would naturally colonize these afforested sites. However, sites planted with only heavy-seeded species are slow to develop vertical forest structure, often requiring 7 to 10 years to emerge from the competing herbaceous vegetation. Vertical forest structure is a key predictor of colonization by forest breeding birds (Twedt and Portwood 1997, Wilson and Twedt In Press).

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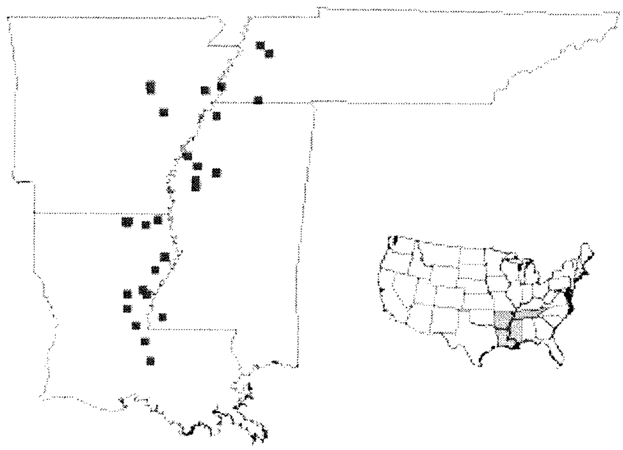

Figure 1—Location of afforested study sites in which we provided supplemental patches of fast-growing trees to enhance habitat for forest birds.

When distance from existing seed sources (i.e., mature trees) is >100 m, woody species (both light- and heavy-seeded) are insignificant invaders (Allen 1990, Wilson and Twedt In Press). This is particularly true in some areas of the Mississippi Alluvial Valley where afforestation occurs several km from extant forests and in areas no longer subject to periodic inundation from flood events that transport seeds. Lack of naturally invading early-successional tree species further restricts the development of vertical forest structure. Under these time and distance constraints, afforested sites may remain inhospitable to colonizing forest avifauna for up to 20 years.

A further limitation on the rapid growth of trees on afforested sites is that typically no weed control is provided for these plantings. The lack of weed suppression, or any other intermediate silvicultural management, has been attributed to limited financial and personnel resources. However, substantial competition from weeds may induce significant mortality of some species of fast-growing trees (Ezell 1994). Given their inability to provide weed control, managers are reluctant to risk increased tree mortality by planting susceptible species.

Regardless of which tree species are planted, species must be compatible with on-site edaphic and hydrologic conditions. However, with species selections that match site conditions, we believe that afforestation that incorporates fast-growing tree species is more conducive than historical afforestation practices to colonization by forest birds (Twedt and Portwood 1997, Twedt and Portwood, in press). Production of short-rotation woody crops, "under-planted" with other forest species, is one agroforestry option that rapidly produces forest conditions. Intercropping or alley cropping (i.e., growing agricultural crops between tree rows) using wide (> 12 m) alleyways represents another transitional agroforestry management option that is particularly suitable for converting large areas of cropland to forest. However, many land managers are reluctant to adopt these progressive methods of afforestation because of (1) an erroneous (in our opinion) perception that the tree species commonly used in agroforestry are not beneficial to wildlife, (2) continued belief that light-seeded species will naturally colonize afforested sites, and (3) lack of resources to ensure adequate weed control for newly established trees. As a compromise step that could provide limited vertical development within sites afforested using traditional methods, we supplemented oak-dominated plantings on bottomland sites with a series of systematically distributed patches of fast-growing trees.

Through the addition of small patches (100 m^2) of eastern cottonwood (*Populus deltoides*) and American sycamore (*Platanus occidentalis*) we sought to promote more rapid development of vertical forest structure and more quickly provide elevated sites for avian perches and nest platforms. We predict that providing rapid vertical structure for perching and breeding birds will increase the recruitment of woody species that use birds as vectors for seed dissemination and promote more rapid colonization of afforested sites by forest birds.

Within this paper, we assess the survival and development of supplemental planted cottonwood and sycamore after their first and second growing seasons. Additionally, we assessed the effect of fertilization, four methods of weed control applied at planting, and tree shelters on tree survival and development.

METHODS

Our study sites were agricultural fields, within the Mississippi Valley and adjacent bottoms, scheduled to be afforested during winter of 1997-98 or 1998-99. All study sites formerly supported bottomland hardwood forests. Each site was planted predominately to oak following traditional afforestation practices of the U.S. Fish and Wildlife Service and USDA Natural Resources Conservation Service. However, because restoration philosophies differed among land managers and because of different soil and hydrology, additional species were planted on some sites and included sweet pecan (*Carya illinoensis*), baldcypress (*Taxodium distichum*), persimmon (*Diospyros virginiana*), or green ash (*Fraxinus*

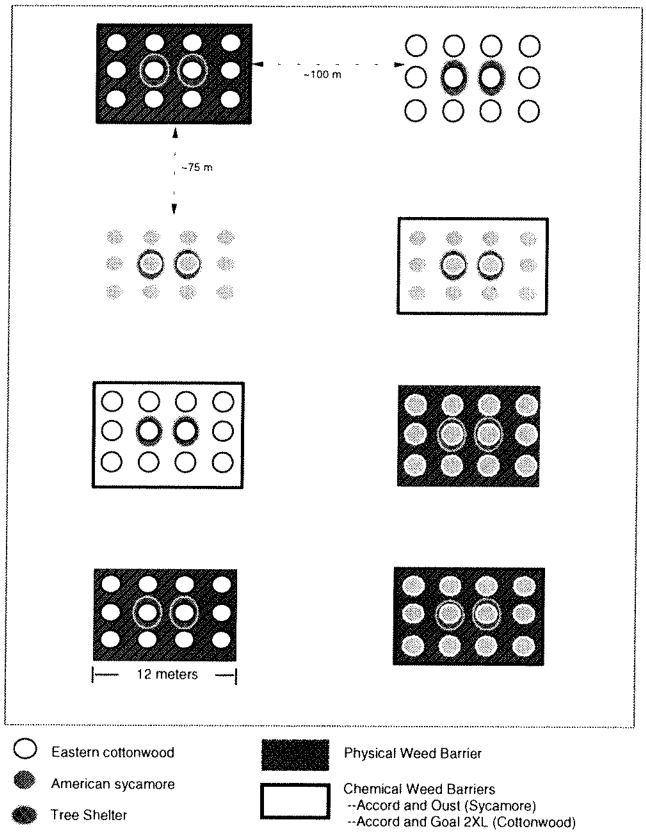

Figure 2—General distribution of 8 randomly assigned treatments (2 tree species x 4 weed control methods) applied to afforested study sites to assess the effect of small patches of fast-growing trees within oak dominated plantings.

pennsylvanica). We planted supplemental tree patches on a total of 40 sites (21 during 1998 and 19 during 1999; figure 1). Sites were disked or mowed before afforestation.

On all treated sites, we randomly applied different treatments to 8 systematically distributed patches using a 2 x 4 factorial design (2 tree species x 4 weed control methods). Our objective was to apply these treatments to patches that were at least 50 m from field edges and 100 m apart (figure 2). However, restrictions imposed by field size and dimensions often reduced between patch distance: the minimum distance between patches was 60 m.

Within each of the 8 treatment patches, we planted 12 trees in a 3-tree by 4-tree grid (figure 2). Trees were 4m apart within this planting grid. Eastern cottonwood was planted in 4 of the 8 patches whereas the other 4 patches were planted with American sycamore. These species were selected because they are often found on bottomland sites during early-succession, and because their use in agroforestry within the Mississippi Alluvial Valley made planting stock readily available. Planting stock was obtained from commercial pulpwood producers (Crown Vantage and Westvaco). We planted 30 centimeter (Crown Vantage) and 45 centimeter (Westvaco) stem cuttings of eastern cottonwood and 1-year-old, bare-root seedlings (Westvaco) of American sycamore. Sycamore seedlings were planted to the root collar as they were growing in the seedbed. All cottonwood stem cuttings planted on a site were from the same source (Crown Vantage or Westvaco) and were vertically inserted into the ground such that 1 to 3 inches were emergent with dormant buds facing up.

Because survival of these fast-growing species is likely enhanced when competition from weeds is reduced (Krinard and Kennedy 1987), we compared the effect of 4 different levels of weed protection. The 4 weed control treatments were: (1) no weed control, (2) physical weed barriers using commercially available wood fiber mats (RTI Mulch Mats, Reforestation Technologies International) or landscape fabric weed barriers (VisPore® Tree Mats, Treessentials Company), (3) single application chemical weed control at planting following practices used and recommended by industrial pulpwood producers, and (4) combined physical and chemical weed control.

On 24 afforested sites (19 during 1997-98 and 5 during 1998-99) we used both wood fiber and landscape fabric weed barriers. Within the patches that received physical weed control or both physical and chemical weed control on these 24 sites, we protected one-half the trees (6 trees) using wood fiber mats and the other half were protected using landscape fabric barriers. We used only landscape fabric barriers on the remaining 16 afforested sites.

Chemical weed control for cottonwood consisted of a single spray at planting of a glyphosate contact herbicide [Accord®] applied at a rate of 64 ounces/acre and a pre-emergent herbicide [Goal 2XL®]) applied at a rate of 64 ounces/acre. A similar dual herbicide treatment was applied to sycamore patches but the pre-emergent herbicide was Oust® applied at a rate of 4 ounces/acre. Pre-emergent herbicides differed between treatments because of industry recommendations and label restrictions. Herbicides were applied only to the vicinity of the planted patches and a small (~ 4 m) buffer. This application resulted in only about 0.1 ha per site treated with herbicide.

Because our objective was to achieve rapid vertical growth of planted trees, we fertilized all supplemental trees on 23 randomly selected sites. On these sites, we buried a 10 g fertilizer packet (18-6-6) or 10 g fertilizer tablet (20-10-5) adjacent to each planted tree.

Additionally, during 1998-99, we attempted to further enhance growth and survival by placing 1-m-tall (3-ft) Supertube® tree shelters (Treessentials Company) around 2 trees within each supplemental patch of trees. The lower edge of each tree shelter was below ground level and they were held upright by 1.2 m tall bamboo stakes.

We assessed survival and development of supplemental trees after 1 and 2 growing seasons. During these assessments, we classified each tree as alive or dead. For each live tree, we measured basal diameter to the nearest

Table 1—Survival (percent), height (centimeters), and basal diameter (millimeters) of American sycamore (*Platanus occidentalis*) and eastern cottonwood (*Populus deltoides*) planted in supplemental patches on afforested bottomlands during 1998-1999 and 1999-2000

Survival or size	Cottonwood	Sycamore
1st Year Survival	24.8 ± 4.6	47.0 ± 4.7
1st Year Height	83.0 ± 2.4	74.7 ± 1.1
1st Year Basal Diameter	14.4 ± 0.3	11.7 ± 0.1
2nd Year Survival of trees alive after 1 year	52.0 ± 6.8	76.9 ± 4.4
2nd Year Height	112.7 ± 3.3	109.2 ± 1.6
2nd Year Basal Diameter	21.8 ± 0.5	16.9 ± 0.3
Survival of re-planted trees	9.1 ± 2.6	35.8 ± 5.8
Survival of all trees after 2 growing seasons	19.0 ± 4.0	44.3 ± 5.3

millimeter and tree height (highest live bud) to the nearest centimeter.

We replanted tree mortalities using subjective criteria within which we attempted to ensure >1 live tree within each supplemental patch within the limitations of available planting stock. Survival of replanted trees was assessed after 1 year (i.e., after the second growing season for the original plantings) but data were maintained separate from data on our original plantings.

ANALYSIS

Mean percent tree survival, mean tree height, and mean basal diameter were compared between fertilizer treatments and among the 8 species-weed control treatments using a split plot analysis of variance (ANOVA). The 40 planted fields were the experimental units for comparing fertilizer treatments (WHOLE PLOTS) whereas the 8 patches of supplemental trees (SPLIT PLOTS) within each field were the experimental units for comparing species and weed treatments (2 species x 4 weed treatments x 40 sites = 320 experimental units). Individual trees within each planted patch were sub-sample units within these experimental units. Thus mean height, mean diameter, and proportion of trees surviving within each patch were the statistics compared. We applied an angular transformation to proportion data before subjecting to ANOVA.

We wrote specific contrast statements within the context of the ANOVA to compare between tree species and among the weed control treatments within each tree species. We assessed the effect of weed control treatments within each of the 2 tree species by writing contrast statements to compare (1) no weed control vs. the mean of the 3 weed control treatments and (2) chemical weed control vs. physical weed barriers. Additional contrasts were made based on the results of these comparisons.

We used separate analyses to compare weed barrier types and tree shelters. To compare weed barrier types we used only data from the 96 patches where we applied both landscape fabric weed barriers and wood fiber mulch mats. Similarly, we used data only from sites where tree shelters were deployed to compare survival and height of trees with and without shelters. Because survival data were categorical, and because the few trees treated within any individual patch (6 trees for barriers, 2 trees for shelters) made computation of proportion survival estimates unreliable, we used logistic regression to compare survival between weed barrier types and between tree shelter treatments. Thus, we assumed weed barrier types and tree shelters were randomly assigned to individual trees. However, we compared tree heights between weed barrier types and between tree shelter treatments using ANOVA wherein barrier type and shelter treatment were SPLIT plots within each species-weed control treatment patch.

RESULTS

After two growing seasons, the mean number of surviving supplemental trees of the 96 originally planted was 26.6 ± 3.6 per site. Five sites had no surviving trees and five additional sites had <10 live trees. The maximum number of surviving trees on any site was 81. Two sites were

Table 2—Mean survival (percent), tree height (centimeters), and basal diameter (millimeters) of eastern cottonwood (*Populus deltoides*) subjected to no weed control (None), physical weed barriers (Physical), herbicide treatment of Accord and Goal 2XL (Chemical), or a combination of physical weed barrier and herbicide (Both) treatments when planted in supplemental patches on afforested bottomlands during 1998-1999 and 1999-2000. Second year survival is with respect to those trees that were alive after one growing season. Height and basal diameter are of live trees

Survival or Size	None	Physical	Chemical	Both
1st Year Survival	17.5 ± 4.5	29.6 ± 5.5	26.5 ± 4.8	25.6 ± 4.9
1st Year Height	66.5 ± 9.2	75.4 ± 8.0	71.2 ± 9.0	79.9 ± 8.8
1st Year Basal Diameter	12.2 ± 1.4	13.6 ± 1.3	12.6 ± 1.5	13.7 ± 1.2
2nd Year Survival	47.8 ± 10.3	64.5 ± 8.4	53.9 ± 8.4	54.4 ± 7.4
2nd Year Height	81.7 ± 12.9	85.0 ± 10.2	94.8 ± 10.5	103.2 ± 14.2
2nd Year Basal Diameter	18.2 ± 1.6	18.2 ± 1.3	18.5 ± 1.3	20.8 ± 1.5

Table 3—Mean survival (percent), tree height (centimeters), and basal diameter (millimeters) of American sycamore (*Platanus occidentalis*) subjected to no weed control (None), physical weed barriers (Physical), herbicide treatment of Accord and Goal 2XL (Chemical), or a combination of physical weed barrier and herbicide (Both) treatments when planted in supplemental patches on afforested bottomlands during 1998-1999 and 1999-2000. Second year survival is with respect to those trees that were alive after one growing season. Height and basal diameter are of live trees.

Survival or size	None	Physical	Chemical	Both
1st Year Survival	48.8 ± 6.4	64.2 ± 6.0	34.8 ± 5.6	40.2 ± 5.4
1t Year Height	69.2 ± 4.1	76.9 ± 4.4	62.3 ± 6.4	59.4 ± 3.9
1st Year Basal Diameter	9.9 ± 0.4	12.0 ± 0.4	10.5 ± 0.8	11.3 ± 0.5
2nd Year Survival	76.7 ± 6.6	87.7 ± 3.8	57.2 ± 8.3	78.7 ± 5.9
2nd Year Height	94.3 ± 8.0	108.9 ± 7.1	91.4 ± 8.1	98.0 ± 4.9
2nd Year Basal Diameter	13.8 ± 0.9	17.1 ± 1.0	14.5 ± 1.2	15.6 ± 0.9

considered complete failures after the first year and were not revisited after the second growing season.

Fertilizer

Application of fertilizer did not effect tree survival ($F_{1,38} = 2.01$, $P = 0.16$), tree height ($F_{1,38} = 1.01$, $P = 0.32$), or tree basal diameter ($F_{1,38} = 1.84$, $P = 0.18$) after the first growing season. This effect of fertilizer application was consistent among the 8 factorial treatments with regard to tree survival ($F_{7,266} = 0.77$, $P = 0.61$), tree height ($F_{7,214} = 1.02$, $P = 0.42$), and tree basal diameter ($F_{7,214} = 1.64$, $P = 0.13$). The mean proportion of surviving trees after the first growing season was 0.43 ± 0.02 (x ± SE) when unfertilized and 0.31 ± 0.02 when fertilized. Tree height, however, was 60.9 ± 3.3 centimeter without fertilizer and 70.3 ± 2.9 centimeter with fertilizer. Similarly, tree basal diameter was 10.6 ± 0.5 millimeter without fertilizer and 12.0 ± 0.5 with fertilizer. Although not statistically significant, the greater height and basal diameter of fertilized trees suggested that fertilization was having a biological effect. If so, this effect was not accentuated during the second growing season. Neither tree height ($F_{7,151} = 0.58$, $P = 0.45$) nor tree basal diameter ($F_{7,151} = 0.01$, $P = 0.93$) differed between fertilizer treatments after 2 growing seasons.

Tree Species

We found significant differences in survival between tree species ($F_{1,266} = 62.7$, $P < 0.01$) with 0.47 ± 0.05 American sycamore and 0.25 ± 0.05 eastern cottonwood surviving after the first growing season (table 1). Of the trees that survived the first growing season, 0.77 ± 0.04 of the sycamore remained alive after 2 growing seasons whereas only 0.52 ± 0.07 of the cottonwood survived the second growing season (table 1). Survival of 331 replanted sycamores (0.36 ± 0.06) was markedly greater than survival of 587 replanted cottonwoods (0.09 ± 0.03) (table 1). After two growing seasons, a total of 741 sycamores and 323 cottonwoods remained alive within supplemental patches.

Despite differences in survival between tree species, mean tree height did not differ between species after either the first ($F_{1,163} = 0.08$, $P = 0.78$) or second ($F_{1,151} = 3.70$, $P = 0.06$) growing season (table 1). However, cottonwood had greater basal diameters than did sycamore after the first ($F_{1,163} = 3.96$, $P = 0.03$) and second ($F_{1,151} = 15.90$, $P < 0.01$) growing seasons (table 1). Mean tree heights increased for both species between the first and second growing seasons (table 1). However, the maximum tree height attained by any tree of 3.0 meters after 1 growing season did not increase after the second growing season (3.0 meters).

Weed Control Treatments

Weed control near cottonwood (table 2) had a positive effect on their first year survival ($F_{1,266} = 6.57$, $P = 0.01$) but did not effect mean tree height ($F_{1,163} = 2.40$, $P = 0.12$) or mean basal diameter ($F_{1,163} = 0.99$, $P = 0.32$). Similarly, second year survival of cottonwood (table 2) was greater with weed control then without weed control ($F_{1,266} = 5.12$, $P = 0.02$) but weed control did not influence second year height ($F_{1,151} = 0.76$, $P = 0.39$) or diameter ($F_{1,151} = 0.33$, $P = 0.56$). Physical and chemical weed control afforded similar survival to cottonwood ($F_{1,266} = 0.58$, $P = 0.45$) and resulted in similar heights ($F_{1,163} = 0.32$, $P = 0.57$) and basal diameters ($F_{1,163} = 0.39$, $P = 0.53$). Further, we detected no synergistic effect of the combination of chemical and physical weed protection on first year survival ($F_{1,266} = 0.23$, $P = 0.63$).

For sycamore, the mean survival of patches with weed control (table 3) did not differ from survival of untreated controls after the first growing season ($F_{1,266} = 0.35$, $P = 0.55$) nor after the second growing season ($F_{1,266} = 0.01$, $P = 0.91$). However, this apparent lack of benefit from weed control was the indirect result of extreme differences in survival between physical weed barriers and chemical weed control (($F_{1,266} = 27.03$, $P < 0.01$). Indeed, treatments that employed chemical weed control on sycamore significantly increased tree mortality over treatments where no herbicide was used ($F_{1,266} = 22.69$, $P < 0.01$). In contrast, physical weed barriers increased tree survival compared to untreated controls ($F_{1,266} = 6.97$, $P < 0.01$).

For surviving sycamore, neither height ($F_{1,163} = 0.06$, $P = 0.80$) nor basal diameter ($F_{1,163} = 3.39$, $P = 0.07$) differed between the mean of all weed control treatments and the untreated control (table 3). However, in addition to limiting survival, chemical weed control reduced tree height (table 3) compared with patches of sycamore where no chemical was applied.

Weed Barrier Type

Tree survival was similar ($x^2 = 0.34$, $P = 0.56$) for trees protected by wood fiber mulch mats (44 percent) and for trees protected by landscape fabric weed barriers (42 percent). Similarly, mean tree height did not differ ($F_{1,54} = 0.73$, $P = 0.40$) between trees protected with wood fiber mats (68.3 ± 3.5 centimeters) and those protected by landscape fabric barriers (67.5 ± 3.9 centimeters).

Tree Shelters

Unexpectedly, survival of trees protected with tree shelters was significantly decreased ($x^2 = 105.55$, $P < 0.01$) by the addition of tree shelters. Only 26 percent of trees in shelters survived compared to 33 percent of trees that were not protected. Moreover, for those trees that did survive the first growing season, protection within tree shelters did not result in a significant increase in height over unprotected trees ($F_{1,48} = 0.31$, $P = 0.57$). After one growing season, the mean height of trees protected by shelters was 85.8 ± 5.8 centimeters whereas mean height of unprotected trees was 76.6 ± 4.1 centimeters.

DISCUSSION

Drought conditions prevailed during the growing season of the 3 years of this study. Long-term average rainfall for April-September in the Mississippi Alluvial Valley at Baton Rouge, LA is 82 centimeters. During our study, rainfall for this 6-month period was 58, 59, and 43 centimeters in 1998, 1999, and 2000, respectively. Physical weed barriers not only limited competition with weeds for moisture but also helped to reduce moisture loss to the atmosphere. However, even with weed protection, survival of supplemental trees, especially cottonwood was below our expectations.

On sites where survival was adequate, vertical development of both species did meet our expectations. In particular, cottonwood on several sites approached 3 m (10 ft) in height after the first growing season. Unfortunately, these were generally the only vertical substrates within these fields and thus, they were used extensively by white-tailed deer (*Odocolyis virginiana*) for browsing and more detrimentally as rubs for their antlers. Rubbing against these saplings invariably removed the cambium and thereby girdled the trees. Thus, during the next year, shoots developed from below the girdled area (usually about 1 meter from the ground). In addition to starting re-growth far below the previous terminal bud, girdling produced multiple competing stems. Because multiple stems compete for resources, vertical development of any single stem was reduced. Thus, our expectation of greatly increased vertical development during the second growing season was not realized.

Because sycamores tended to be smaller and developed many more lateral branches during their first growing season, deer rubbing of sycamore was not a significant problem after the first growing season. However, after 2 growing seasons, sycamores were incurring the same damage from deer rubbing that cottonwoods previously received. Furthermore, it appears that girdling of stems by deer will continue to be a recurring problem during tree dormancy.

The effect of chemical weed control on sycamore survival varied among sites but complete mortality of all trees and herbaceous vegetation within patches treated with Oust was not uncommon. We recalibrated spray equipment, verified application rate prior to planting, and took care to avoid spraying directly on planted seedlings during the second year of our study but increased mortality of sycamore within treated patches persisted. Soil conditions, particularly soil PH, likely contributed to the excessive mortality of sycamore associated with herbicide treatment.

Although we had hoped for greater survival of supplemental trees, we believe that the >10 trees that survived on 30 of our 40 study sites will be adequate to assess the effect of this technique on woody species diversity and avian colonization. An additional set-back was the small increase in vertical development after the first growing season. However, surviving trees likely have established root systems and substantial increased growth is likely during the next 3 years. As we do not plan to evaluate woody species diversity or bird response until 5 or 6 years after establishment, this time frame should be sufficient to provide supplemental trees that are well above the herbaceous vegetation and much taller that the trees planted via traditional afforestation methods. Indeed, observations by the author (DJT) indicate that supplemental patches are obvious anomalies within these otherwise homogeneous fields. Additionally, several bird nests, including at least one shrub nesting species (Orchard Oriole [*Icterus spurius*]), were built in supplemental trees during their second growing season. Therefore, we are hopeful that provision of these few supplemental patches of fast-growing trees within the context of large afforested sites will attract forest birds and ultimately will yield a more species rich forest at maturity.

RECOMMENDATIONS

When extending this concept from research to operational afforestation practice, we recommend increasing the number of species that are candidates for placement in small patches. Additional species that could be planted in supplemental patches include: honey locust (*Gleditsia triacanthos*), yellow poplar (*Liriodendron tulipifera*), sweetgum (*Liquidambar styraciflua*), or where non-native species are acceptable, royal paulownia (*Paulownia tomentosa*). Because we planted eastern cottonwood and American sycamore on all study sites, we made no attempt to ensure tree species compatibility with soil type or hydrology. However, planting only species that are compatible with site conditions should increase tree survival.

To increase the likelihood that some trees will survive within each supplemental patch, we recommend planting 2 or more tree species within each patch. Further, we recommend providing protection from weed competition through use of weed barriers. Planting more than 12 trees within a patch, for example 18 or 24 trees, increases the probability that at least some of these trees will be overlooked by deer and will exhibit substantial height increases between years.

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BALDCYPRESS RESTORATION IN A SALTWATER DAMAGED AREA OF SOUTH CAROLINA

William H. Conner and Mehmet Ozalp[1]

Abstract—Baldcypress (*Taxodium distichum* (L.) Rich.) seed was collected in 1992 from nine different estuarine areas in the southeastern United States (Winyah Bay, SC, Ogeechee and Altmaha Rivers in GA, Loftin Creek, FL, Ochlockonee River FL, Mobile Bay, AL, West Pearl River, LA, Bayou LaBranche, LA, and Lake Chicot, LA) and planted in Clemson University's Hobcaw nursery in the spring of 1993. Germination ranged from a low of 16 percent for seed from FL to 58 percent for seed from NC. Seedlings were grown in the nursery for two growing seasons, lifted, and planted in an area killed by saltwater introduced by Hurricane Hugo's (1989) storm surge. Half of the seedlings were protected with tree shelters. Seedlings averaged 122 cm tall upon planting. Survival after 6 years was 99 percent. Height growth of seedlings in tree shelters was significantly higher than those not in tree shelters for each year except during year 3. Among the seed sources, seedlings from the Loftin Creek, FL source have shown greatest growth, with and without protection, for all growing seasons except the first year. After 6 years, average height of tree-shelter protected seedlings was 393 cm while the average height of non-protected seedlings was 281 cm. Tree-shelters increased early growth of seedlings, but once they emerged from the tree-shelter, growth differences between shelter and no-shelter treatments decreased and seems to be more related to the degree of deer herbivory experienced by unprotected seedlings.

INTRODUCTION

Low-lying coastal forested wetlands are particularly vulnerable to saltwater intrusion. Subsidence and sea level rise along the Northern Gulf of Mexico coast are causing increased flooding and saltwater intrusion into freshwater areas (Guntenspergen and others 1998). As a result, baldcypress (*Taxodium distichum* (L.) Rich.) and water tupelo (*Nyssa aquatica* L.) forests are being killed (Allen 1992, Krauss and others 2000, Pezeshki and others 1990). In addition, saltwater flooding caused by storm surges can significantly alter forest communities (Conner 1993, Gresham 1993, Williams 1993), and it may take years before the forest recovers (Conner 1995). Hurricanes are recognized as a normal part of the climatic regime, and natural ecosystems have developed morphologically and ecologically to aperiodic disturbances (Conner and others 1989, Pimm and others 1994). Hurricane wind damage is related to storm intensity, duration, forest structure, and soil conditions (Gresham and others 1991, Loope and others 1994). Forests generally recover quickly from wind damage. However, areas impacted by saltwater intrusion may require artificial regeneration in order to ensure adequate stocking. For example, when Hurricane Hugo came ashore north of Charleston, South Carolina on September 21, 1989, its storm surge was estimated to be as high as 3 m at Georgetown (Williams 1993). High winds and saltwater intrusion damaged an estimated 1.8 million ha (about $1 billion worth of timber) of South Carolina's forests (Hook and others 1991, Marsinko and others 1993).

Previous studies have shown some promising results indicating that baldcypress may tolerate some degree of salinity (0-8 ppt). Studies in Louisiana have shown that substantial intraspecific variation in salt tolerance exists within baldcypress populations (Allen 1994, Allen and others 1994, Krauss and others 1998, Pezeshki and others 1995). These studies were conducted under greenhouse conditions. The only field study that could be found was that of Krauss and others (2000), who planted baldcypress seedlings grown from seed collected in Louisiana, Mississippi, and Alabama. Survival and growth of baldcypress seedlings varied significantly among different salinity, hydrologic, and vegetative combinations in areas impacted by saltwater intrusion, and certain genotypes of baldcypress maintained greater height growth when planted in degraded wetlands.The major objective of this project was to determine if there are baldcypress populations in the southeastern United States that can survive and grow in saltwater damaged areas. A secondary objective was to determine whether or not using tree-shelters would increase survival and height growth of planted baldcypress seedlings.

MATERIALS AND METHODS

Hobcaw Forest is located 7 km southeast of Georgetown, SC (figure 1). A portion of the forest on the western edge of the property was damaged by saltwater intrusion when Hurricane Hugo's storm surge flooded the forest in September 1989. The impacted forest was originally dominated by baldcypress. The soil is a Hobcaw soil (fine-loamy, siliceous, thermic, Typic umraquults), very poorly drained, and moderately permeable with less than 2 percent slopes. Although high concentrations of salinity were found in the site up to 30 months after the hurricane (Williams 1993), there was no detectable salinity at the time of planting.

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Table 1—Height (cm) of baldcypress seedlings from 9 seed sources after 6 growing seasons in a South Carolina wetland forest damaged by Hurricane Hugo's storm surge. See text for explanation of seed source code names. Values in a row with unlike lower case letters are statistically different at an alpha level of 0.05

	Seed source								
Year	SC	ELA	SGA	WFL	SLA	EFL	CLA	NGA	AL
1995	142bc	147bc	150ab	137c	155a	151ab	142bc	144bc	142bc
1996	157c	164bc	168bc	164bc	175ab	181a	160bc	160bc	159bc
1997	172c	178bc	184bc	181bc	195ab	206a	181bc	182bc	176bc
1998	213c	227bc	229bc	228bc	251ab	273a	226bc	231bc	213c
1999	257c	290bc	277bc	288bc	316ab	345a	280bc	291bc	266c
2000	292c	330bc	323bc	347bc	369ab	407a	321bc	346bc	313bc

Baldcypress seeds were collected in November 1992 from seven estuarine areas subject to tidal influence (Winyah Bay, SC=SC; Ogeechee River, GA=NGA; Altamaha River, GA=SGA; Flint River, FL=EFL; Ochlockonee River FL=WFL; Mobile Bay, AL=AL; Bayou LaBranche, LA=SLA) and two freshwater areas (West Pearl River, LA=ELA; Lake Chicot, LA=CLA) (figure 1). Cones were collected from five trees at each site, air-dried, crushed to separate the seed, mixed with wet sand, and stored in plastic bags between 4 and 8 degrees C for 90 days.

After stratification, the seeds were planted in the Hobcaw nursery in the spring of 1993. After two growing seasons, the seedlings were lifted and prepared for planting by cutting all lateral roots off and cutting the tap root to approximately 23 cm (Conner and others 1999). The root-pruned seedlings were wrapped in moist peat and transported to the field where they were planted in an area killed by saltwater from Hurricane Hugo's storm surge. Tree shelters were placed on one half of the seedlings. Height growth was measured each year from 1995 to 2000. Statistical analyses of the data were done using a completely randomized design for repeated measurements with factorial arrangement between nine seed sources, two tree-shelter treatments, and six growing seasons.

RESULTS

Survival rates for all seed sources was high. After six growing seasons, survival for all trees was 99 percent. Only four trees died during the study and all of them were non-sheltered trees.

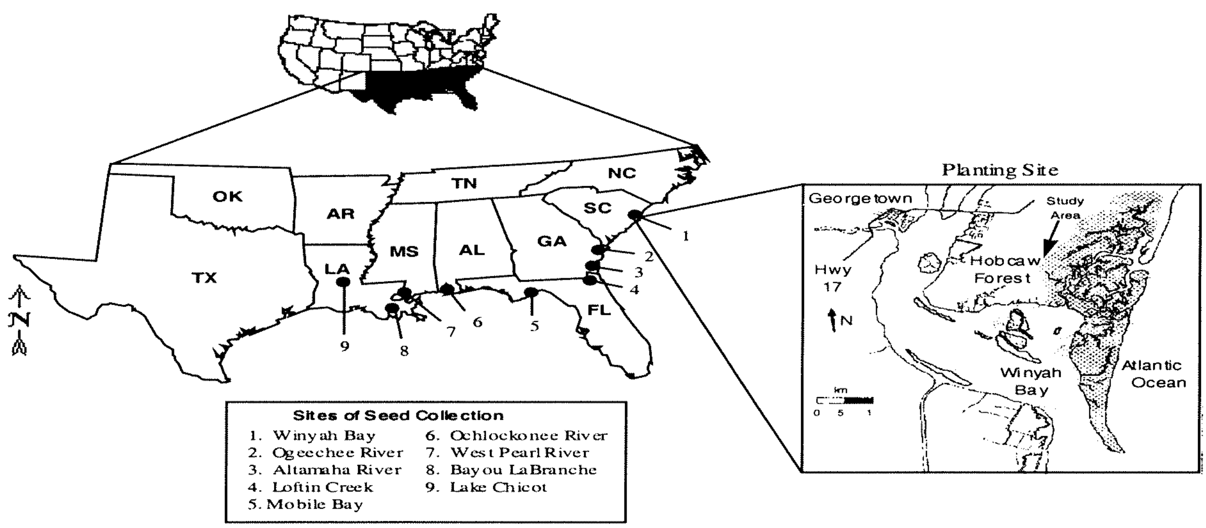

Figure 1—Map of the southern United States showing baldcypress seed collection sites and the South Carolina planting site.

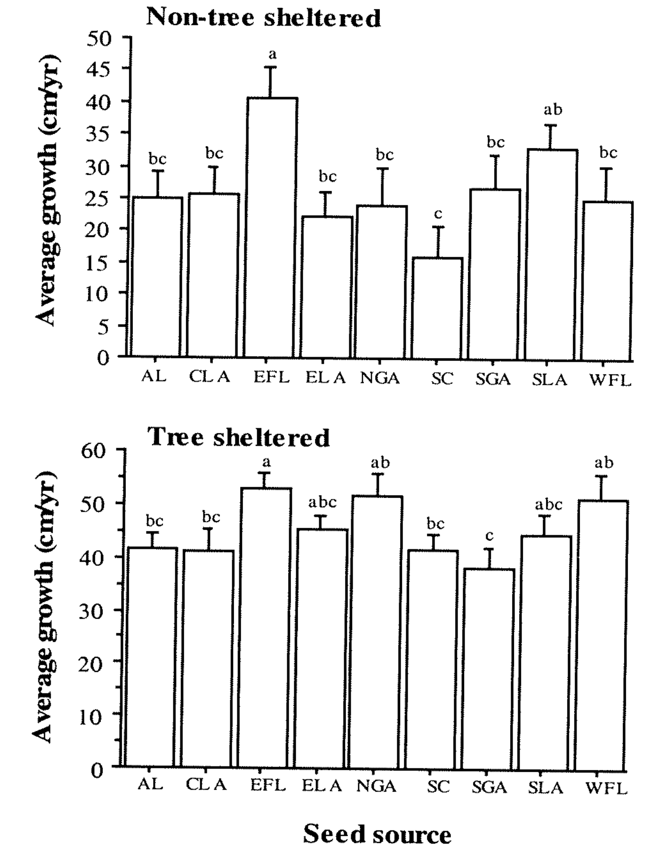

Figure 2—Average annual height growth (cm) of baldcypress seedlings planted in South Carolina with and without tree shelters. Error bars represent ±1 S.E.

After six growing seasons, average height of tree-shelter protected seedlings was 393 cm while the average height of non-protected seedlings was 281 cm. Growth of seedlings in tree shelters was significantly greater than for non-shelter seedlings except during the third growing season when both sheltered and non-sheltered seedlings increased by an average of about 17.8 cm/yr in height (figure 2). Overall, sheltered seedlings grew an average of 44.7 cm/yr while non-sheltered seedlings grew 25.4 cm/yr. All seedlings grew better after the third growing season. During the first three growing seasons, seedlings average growth was 20 cm/yr, but growth more than doubled for growing seasons 4 through 6.

Among seed sources, seedlings from east Florida (EFL) and south Louisiana (SLA) have shown the greatest growth by an average of 44.1 and 38.9 cm/yr, respectively. However, only EFL seedlings grew significantly better than all other seed sources (except those from SLA). The rest of the seed sources exhibited similar growth rates, and they were not significantly different from each other.

Growth differences were more readily noticeable in non-sheltered trees than in sheltered ones (figure 3). Growth of the non-sheltered EFL seedlings was significantly greater than all others sources other than SLA. In the sheltered seedlings, however, growth differences were less distinct. Although EFL seedlings had the highest average annual growth rate, they were not significantly greater than seedlings from ELA, NGA, SLA, or WFL.

Final heights of seedlings after six growing seasons in the field varied from a low of 292 cm for SC seedlings to a high of 407 cm for EFL seedlings (table 1). The EFL seedlings have grown the best in the planted site for five of the six years measured. During the first year, SLA seedlings were the tallest (155 cm), but not significantly so.

DISCUSSION

Coastal forests are increasingly being subjected to increased flooding and salinity levels. The impact is widespread and can be detrimental to these forests (Allen 1992, Conner 1994, Pezeshki and others 1990). Previous studies have examined species-level responses to salinity increases (Conner 1994, Conner and Askew 1994, Conner and others 1997, McLeod and others 1996) as well as family-level variations (Allen 1994, Allen and others 1994, Krauss and others 1998, Pezeshki and others 1995). Current research is aimed at finding and/or improving the tolerance of baldcypress for use in restoration projects in swamp forests damaged by saltwater intrusion (Allen and others 1994, Krauss and others 2000).

Baldcypress has demonstrated significant intraspecific variation in treatments as high as 8 ppt (Allen and others 1994), but beyond that, mortality is likely (Conner and others 1997). Interestingly, genotypes of baldcypress with the greatest amount of tolerance to salinity are not always found in brackish water seed sources. Krauss and others (2000) found that freshwater seed sources in their study were among the top performers under saline conditions in terms of height growth. The best performers in this study were from the more brackish areas, even though the site retained no measurable salinity.

Overall, all baldcypress seedlings from the nine sources in this study had high survival rate and good height growth in the saltwater damaged area. After six growing seasons, the area

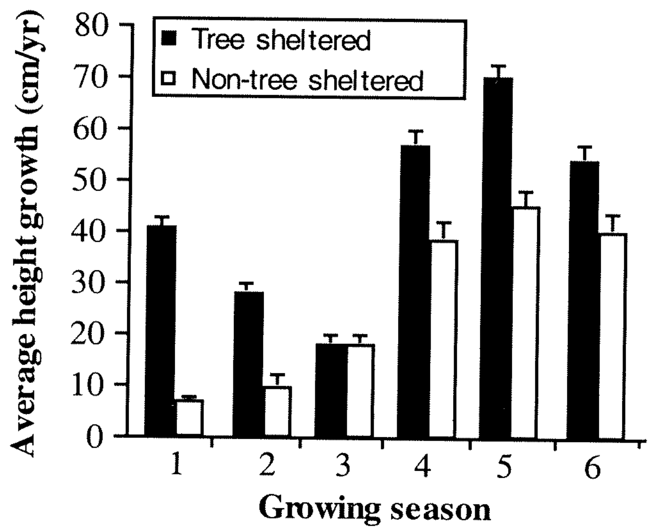

Figure 3—Average height growth of baldcypress seedlings with and without tree shelters by seed source. Error bars are ±1 S.E. and different lower case letters represent a significantly significant difference with an alpha level of 0.05

shows signs of success with respect to restoration efforts (i.e. planted seedlings are beginning to produce seed and young seedlings were observed in the area around the planted seedlings). These findings suggest that an adequate stocking of baldcypress in this saltwater storm surge damaged area has been accomplished through planting. In addition, protecting young seedlings with tree shelters improves early survival and growth and are recommended in areas where herbivory might be a problem.

ACKNOWLEDGMENTS

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FIRST-YEAR EFFECTS OF PLASTIC TUBE SHELTERS, WIRE CAGES, AND FERTILIZATION ON PLANTED NUTTALL OAK SEEDLINGS

Troy S. Taylor and Michael S. Golden[1]

Abstract—A Study was implemented in western Alabama to compare the growth and survival of Nuttall oak (*Quercus nuttallii*) seedlings using plastic tube shelters, wire browse protection, fertilization, and control. A total of 324 Nuttall oaks were planted at a bottomland site in Greene County, Alabama. One-third of the seedlings were enclosed in 48-inch tall opaque plastic shelters. One-third of the seedlings were encircled with 48-inch tall wire fencing. The remaining seedlings were left as control. Fertilization tablets were supplied to one-half of all seedlings in each protection treatment. Black plastic mulch mats were utilized with all seedlings to help suppress herbaceous weeds. Initial measurements on seedling height and caliper growth were taken after planting in March 2000. First year growth measurements were taken in January 2001 and will be remeasured each winter thereafter. Plastic tube shelters stimulated both greater seedling height and diameter growth, compared to the wire cages and control treatments. Furthermore, fertilized seedlings exhibited significantly greater height growth and diameter growth compared to those without. Incidence of animal browse was significantly reduced by the presence of seedling protection devices.

INTRODUCTION

The reproductive characteristics of some of the most desirable timber and wildlife tree species, particularly the oaks, create special problems in successfully reproducing them after a harvest. Due to the thousands of mismanaged acres of bottomland forests that exist in Alabama from past high-grading, the oak component in many floodplains is scattered and of poor quality. High-quality sites that have been harvested commonly experience widespread oak regeneration failures. This is a critical problem because the oak species group is one of the major and more valued for the hardwood products industry (Aust and others 1984). The failures range from almost a complete loss of the oak component to a reduction in the relative dominance of oaks in the stand when compared to the composition of the pre-harvest stand (McGee and Loftis 1993). Sander and Graney (1993) report that although oaks are among the most abundant overstory species in many stands, they are often replaced in the reproduction that follows harvesting because of lack of adequate oak advance reproduction. Obtaining adequate oak regeneration is especially difficult on highly productive sites where understories are often well developed and dominated by shade-tolerant species. Often times advance oak regeneration is present in the understory but is outgrown and shaded out by competitor species.

At all sizes, oaks do not survive and grow well in dense, shaded conditions. Even in full sunlight, germinating seedlings allocate much of their growth to their root systems in the first few years and exhibit slow early height growth. The paradox is that developing oak regeneration on productive sites has been difficult because stand prescriptions that encourage oak regeneration are the same conditions which favor the development of potentially faster growing competitor species (Kormanik and others 1995).

A multitude of plant species are able to germinate in the open-light conditions after a harvest on fertile floodplain soils. Many of these have the potential to restrict oak reproduction by creating conditions unfavorable to oaks. For high quality sites that are prone to natural regeneration failures, artificial regeneration can offer an alternative and viable solution. For artificial regeneration to be successful in highly productive river bottoms, some precautions need to be taken to ensure seedling survival and growth. There are two factors that need to be carefully considered when planting oak seedlings along river bottoms in the South: (1) the faster growing competitor species (vines, undesirable tree species, and herbaceous weeds), and (2) the high population density of white-tailed deer (*Odocoileus virginianus*) and, occasionally, of feral pigs as well. To address these issues it is necessary to protect seedlings from animal browse while at the same time creating and environment conducive to seedling height growth.

OJECTIVES

The objectives of this study are to determine whether there are differences in the growth, survival and animal browse intensity on planted Nuttall oak seedlings which have been subjected to various combinations of plastic tube shelters, wire cages, artificial mulch mats, and fertilizer tablets.

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METHODS/PROCEDURES

A recently cutover bottomland site was located north of Demopolis in Greene County, Alabama, in the floodplain of the Black Warrior River. Two planting areas were located at this site and their boundaries were marked. In the spring of 2000, a total of 324 Nuttall oaks were planted in holes dug using a portable gas-powered auger with a 6-inch bit. Three protection treatments were utilized—plastic tube shelters, wire cages, and control (no protection). One half of all seedlings of each protection type were fertilized at the time of planting with two 10-gram fertilization tablets (20-10-5). Approximately two cups of water were applied to each seedling one week after planting to aid in moisturizing the root systems due to a coincident drought. After planting, seedling height and caliper (at 1-inch above groundline diameter) were recorded. In January of 2001, seedling height and caliper were again recorded, and a measure of browse intensity was documented. At the end of the second growing season, seedling height and caliper will once again be measured, and a portion of seedlings within each protection and fertilization type will be excavated so that differences in root biomass can be examined.

EXPERIMENTAL DESIGN

1-0 Nuttall oak seedlings were obtained from E.A. Hauss Nursery in Atmore, AL, and stored in refrigerated coolers until planted in February, 2000. 162 seedling pairs were planted at the study site. Seedlings were planted at 20-ft by 20-ft spacing. Fertilizer application and seedling protection type were assigned randomly. All protection/treatment combinations were represented equally with 27 seedling pairs (54 total seedlings) for each of the six combinations of protection and treatment (plastic tube shelter, wire cage, control—with and without fertilizer application.

RESULTS

General Linear Model analyses were used to examine the relationships between treatment/protection type and first-season seedling height and groundline diameter growth. The first analysis was computed with height growth as the dependent variable and protection and fertilization class as independent variables. Results were significant: R-square = 0.5655, P = 0.0001 for protection and P = 0.0293 for fertilization. The interaction of protection type and fertilization was not significant for seedling height growth.

The second analysis was computed with first-season groundline diameter growth as the dependent variable and protection and fertilization class as the independent variables. Results were significant: R-square = 0.1431, P = 0.0009 for protection and P = 0.0010 for fertilization. The interaction of protection type and fertilization was not significant for seedling groundline diameter growth.

For seedling height growth, Duncan's Multiple Range Tests indicated significant differences among the means of protection type used. The use of plastic tube shelters stimulated greater height growth among seedlings than either the use of wire cages or control (table 1). There were no significant differences between seedling mean height growth of either wire cages or the control seedlings. Additionally, there were significant differences in seedling height growth for fertilizer application. Fertilized seedlings exhibited significantly greater height growth in the first growing season than those unfertilized (figure 1).

For seedling groundline diameter growth, there were also significant differences among the means of protection types used. The use of plastic tube shelters stimulated greater groundline diameter growth than seedlings utilizing wire cages or the control group (table 1). There were no significant differences between the mean diameter growth of seedlings of the wire cages and control seedlings. Fertilized seedlings exhibited significantly greater groundline diameter growth in the first growing season than those unfertilized (figure 2).

Seedlings protected by either the opaque plastic tube shelters or the wire cages experienced very little damage due to browse, and then only if the terminal bud had protruded

Table 1—Mean first-season height and diameter growth by protection type and fertilizer use. Protection types are as follows: S - plastic tube shelter, W - wire cage, C - control, no protection. Means followed by the same letter within the same column are not significantly different at the alpha = 0.05 level

Protection type	N	Mean height growth (cm)	Mean GLD growth (cm)
S	54	50.06a	4.51a
W	54	11.74b	3.69b
C	54	6.78b	3.28b

Fertilization application	N	Mean height growth (cm)	Mean GLD growth (cm)
yes	81	25.90a	4.27a
no	81	19.82b	3.38b

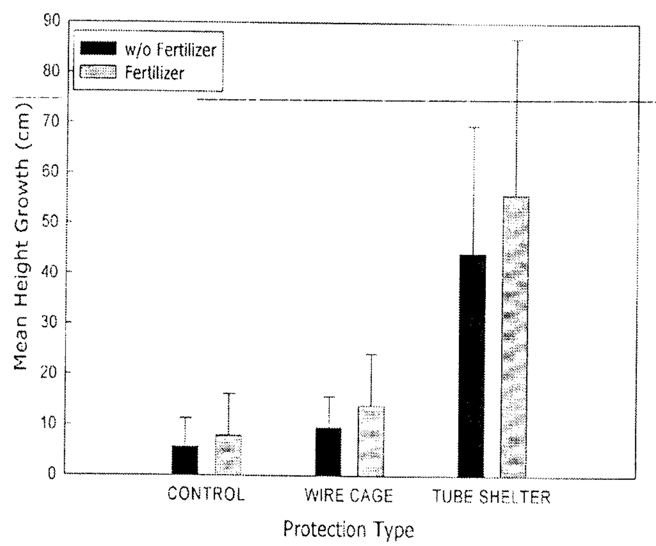

Figure 1—Mean height growth of Nuttall oak seedlings by protection type after one growing season.

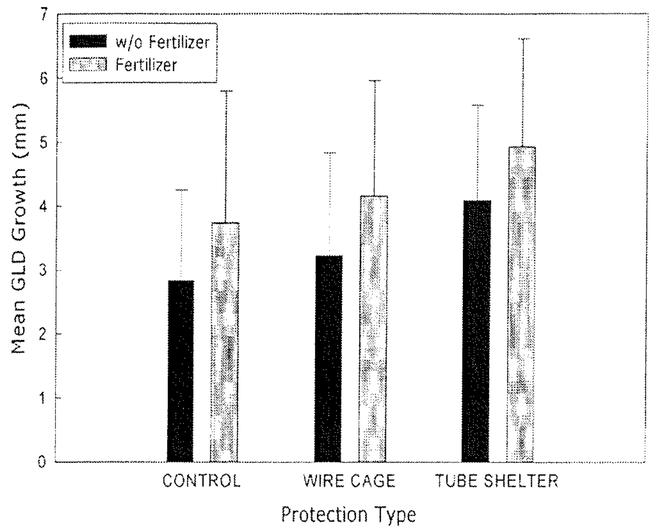

Figure 2—Mean GLD growth of Nuttall oak seedlings by protection type after one growing season.

through the top of the protection device. In contrast, 95.4 percent of the unprotected (control) seedlings were damaged by animal browse of some type and no longer retain their terminal buds. Of these, 28.2 percent of seedlings sustained browse heavy enough to cause extensive forking along the bole while 67.2 percent have only been slightly browsed (figure 3).

CONCLUSIONS

The 48-inch tall opaque plastic shelters stimulated both greater seedling height and groundline diameter growth compared to those enclosed in wire cages or those in the control treatments. Also, fertilized seedlings exhibited significantly greater seedling height growth and groundline diameter growth compared to those utilizing no fertilizer. Incidence of animal browse was significantly reduced by the presence of seedling protection devices.

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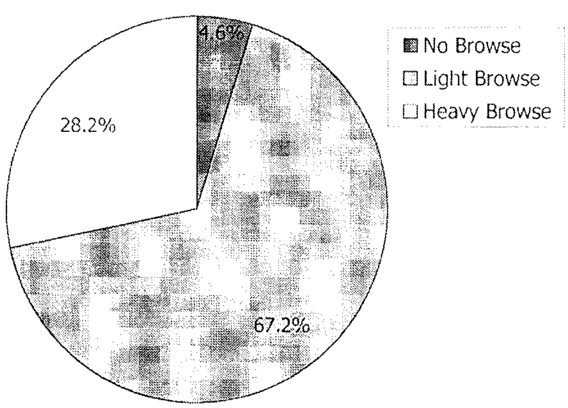

Figure 3—Browse incidence of unprotected (control) Nuttall oak seedlings after one growing season.

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EFFECTS OF LIGHT REGIMES ON 1-YEAR-OLD SWEETGUM AND WATER OAK SEEDLINGS

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Abstract—Light regimes vary significantly within small forest openings, ranging from full sunlight to total shade. This may affect establishment, early growth, and competitive status of hardwood seedlings. We used modified shadehouses to simulate light conditions within forest openings and to test the effects of daily photosynthetically active radiation and time of direct light exposure on growth of sweetgum (*Liquidambar styraciflua* L.) and water oak (*Quercus nigra* L.) seedlings. The study was a split-plot design in a completely randomized block layout with four replicates. The five light regime treatments representing the time of exposure to direct sunlight were NO, NOON, MORNING, AFTERNOON, and FULL. Greenhouse-raised sweetgum and water oak seedlings were planted in the treatment plots at a 0.3 x 0.3 meter spacing in early May 2000. Height, groundline diameter, and leaf surface area were determined at the end of the first growing season. Growth for both species generally increased with the amount of direct sunlight received. For treatments receiving some direct sunlight, sweetgum and water oak were the same height at the end of the growing season. However, sweetgum was 35 percent taller than water oak in the fully shaded treatment. For sweetgum, surface area of the average leaf was significantly larger in the fully shaded treatment than in other treatments, but no treatment differences occurred for surface area in water oak. Results suggest that sweetgum seedlings are more adaptive to low light levels than water oak seedlings during the first year of development.

INTRODUCTION

Oak seedlings are shade intolerant to intermediately intolerant and do not grow well under a closed forest canopy (Smith 1992). Once advanced oak reproduction is established, seedlings need adequate light to grow faster than competing vegetation (Minckler 1957, Bey 1964, Sander 1972, Johnson 1979). Light conditions under a canopy can be complex; direct and partial sunlight may reach seedlings during certain times of a day, but seedlings may be fully shaded at other times. A complex light regime with fluctuating periods of direct and indirect sunlight is difficult to mimic but may strongly affect seedling establishment and growth. Gardiner and Hodges (1998) used shadehouses to study the effect of various light conditions on cherrybark oak (*Quercus pagoda* Raf.) seedlings and found that height of 2-year-old seedlings was greatest with 27 and 53 percent of full sunlight. Groundline diameter showed a similar pattern, except that it was greater with 53 percent of full sunlight than with 27 percent. Similar results have been reported by others (Kolb and Steiner 1990a, 1990b; Gottschalk 1994).

Sweetgum (*Liquidambar styraciflua* L.) and water oak (*Q. nigra* L.) are widely distributed in the southeastern United States and have a very similar range (Kormanik 1990; Vozzo 1990). Both species are commercially important within the region. Sweetgum is a rapidly growing, pioneer species while water oak is a medium-sized rapidly growing species. Sweetgum and water oak are potentially major competitors because of their common occurrence. We hypothesized that timing and amount of photosynthetically active radiation (PAR) would affect the growth and characteristics of sweetgum and water oak seedlings. To test this hypothesis, we designed a non-traditional type of shadehouse to simulate the light conditions occurring within small forest openings. Each shadehouse had sections that had no shade cloth on top, which allowed direct sunlight to reach seedlings during different times of day. Applying the methods of Marquis (1965) and Satterlund (1983), we calculated the length of time seedlings were exposed to direct sunlight and tested the hypothesis that the timing and amount of direct sunlight and daily PAR affected seedling growth.

METHODS

The study site was located in Drew County, AR in the West Gulf Coastal Plain. The soil is an Amy silt loam (Typic Ochraquults). Site index for sweetgum and water oak is about 26 meters at 50 years. Before the study was established, the area was an open field, but native vegetation is classified as mixed pines and hardwoods (Larance and others 1976). Annual precipitation averages 134 centimeters, with most occurring in winter and early spring.

The study was a split-plot design in a completely randomized block layout with four replicates. The main plot was exposure to direct sunlight, and subplot was tree species. With the shadehouses oriented toward north, five light regimes were created based on when direct sunlight

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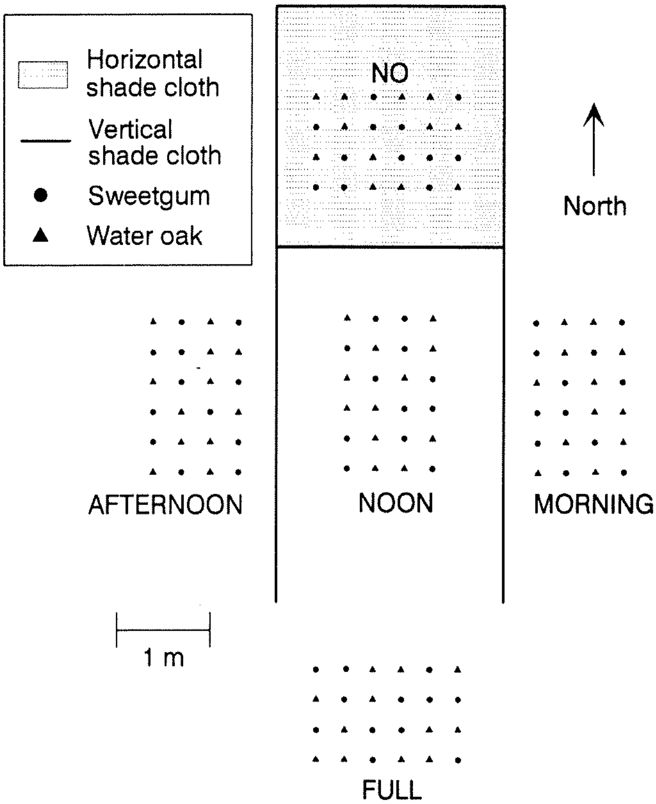

Figure 1—Layout of a modified shadehouse used to create different light regimes for sweetgum and water oak seedlings.

occurred: mostly in the morning (MORNING), around noon (NOON), mostly in the afternoon (AFTERNOON), all day (FULL), and at no time (NO). Shade for the MORNING and AFTERNOON treatments came from the vertical walls (2.4 m tall) of the NOON treatment (figure 1). All shade cloth provided 20 percent of full sunlight. The shadehouse for the NO treatment had shade cloth on the top and all sides except for the lower half of the north side. The NOON treatment only had vertically-oriented shade cloth on the north, east, and west side. The treatments were intended to represent the light conditions occurring within a small forest opening: FULL at the center of a large opening, NO at the south end, MORNING at the western edge, AFTERNOON at the eastern edge, and NOON at the center and northern edge of smaller openings.

Seeds from about 20 open-pollinated trees for each species were collected in Drew County, AR in November 1999, float tested, and stored in a refrigerator at 4 degrees Centigrade. Seeds were stratified for 30 days before germinating in a peat-vermiculite mixture under greenhouse conditions in mid-February. Seedlings were field planted during early May 2000.

Twelve seedlings of each species were planted in each plot with a 0.3 x 0.3 meter spacing in six rows by four columns or four rows by six columns for a total of 480 seedlings in the study. Two seedlings of each species were randomized within each row or column containing four seedlings. During the first month after the planting, we replaced dead seedlings with live seedlings of the same species. Weed-free cloth was used to prevent herbaceous plant competition within the beds. Herbaceous vegetation outside of the beds was periodically controlled with a foliar-applied herbicide. Seedling beds were irrigated to field capacity about weekly from July to September 2000 because of severe drought conditions.

A LI-190SA quantum sensor (LI-COR, Inc. Lincoln, NE) was installed in each treatment of one shadehouse. The calibrated sensors allowed determination of mean PAR for each treatment. PAR was automatically recorded by a LI-1000 data logger (LI-COR, Inc. Lincoln, NE) at a 15-minute interval for 2 days a week beginning in July and ending in early October 2000. The average PAR for each 15-minute interval was calculated for each treatment over the monitoring period, and total daily PAR was computed by adding all the measurements for the average day. Air temperature of one shadehouse was monitored by HOBO Pro Series temperature data loggers (Onset Computer Corporation, Pocasset, MA) throughout the growing season at 5-minute intervals. Temperature sensors were located 30 centimeters above the ground and were protected by white-plastic radiation shields. Soil moisture was monitored by Moisture Point probes (Gabel Corporation, Victoria, Canada) in each bed of all shadehouses. Soil moisture was determined about 7 days after irrigating to field capacity from July to early October 2000.

Seedling height and groundline diameter were measured in October 2000. Forty-eight fully developed leaves from each species and bed were randomly collected, and leaf area and dry weight were determined. Analysis of variance for a split-plot design was conducted on height, groundline diameter, leaf characteristics, and soil moisture using SAS procedure GLM (SAS 1990). Light regime treatments were main effects, and species or soil monitoring depth were subeffects. Replicates for height and diameter were the means for the 12 seedlings of each species in each bed of the four shadehouses, while replicates for leaf characteristics were the means of 48 leaves per species from each bed. Replicates for soil moisture were the means of eight measurements made at a specific depth for each bed from July to early October. Significance was accepted at $\alpha = 0.05$.

RESULTS AND DISCUSSION

The light regimes affected when and how much direct sunlight the seedlings received, and this was reflected in the amount of PAR. The shadehouses created a 3.2-fold difference in PAR across all treatments, and mean daily value was as follows: NO (10), NOON (19), MORNING (27), AFTERNOON (28), and FULL (32 moles per square meter per day). Treatments also differed in mean duration of direct sunlight exposure at ground level from May through October: NO (0.0), NOON (3.4), AFTERNOON (8.5), MORNING (8.4), and FULL (13.0 hours per day).

Air temperature during the day reflected the exposure of beds to direct sunlight (figure 2). In the morning, only the MORNING and FULL treatments received direct sunlight, and this elevated air temperature by 1.0 degree Centigrade over shaded treatments. At noon, all treatments except the NO treatment were in direct sunlight, and air temperature was elevated by an average of 2.4 degrees Centigrade. In

Table 1—Effect of light regime on the mean properties of leaves of sweetgum and water oak seedlings at the end of the first growing season

Direct sunlight exposure	Weight (g/leaf)	Area (cm^2/leaf)	Specific leaf area (cm^2/g)
		---------------Sweetgum---------------	
NO	0.30	59	195
NOON	0.33	48	148
MORNING	0.31	39	125
AFTERNOON	0.31	39	126
FULL	0.35	36	105
		---------------Water oak---------------	
NO	0.11	14	136
NOON	0.14	17	122
MORNING	0.15	16	109
AFTERNOON	0.13	14	106
FULL	0.16	15	99

the afternoon, the FULL and AFTERNOON treatments were the only treatments in direct sunlight, and their temperature was 1.5 degrees Centigrade higher than the treatments in shade.

Water utilization was also affected by exposure to direct sunlight (figure 3). Approximately 7 days after watering to field capacity, volumetric moisture content of the soil was lowest for the FULL treatment and highest for the NO treatment for all monitored depths. Most of the water was apparently transpired because the weed-free cloth and mulch greatly reduced soil evaporation. The differences among light regime treatments and depths were significant for soil moisture (P<0.003) but their interaction was not (P=0.16).

There was no difference in seedling mortality among the treatments, which averaged less than 1 percent for both

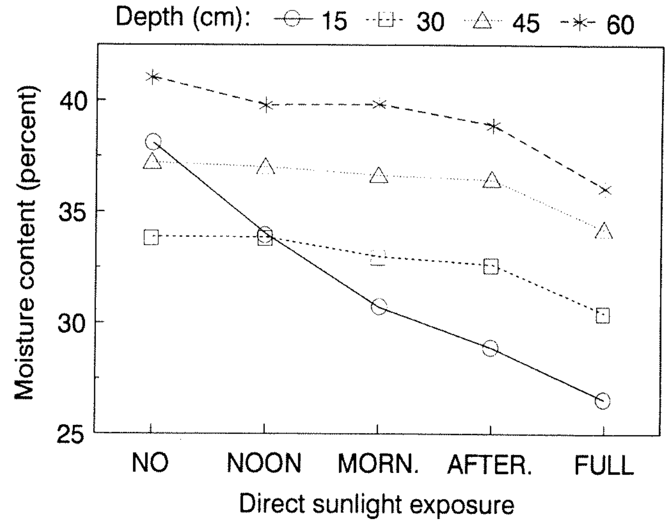

Figure 3—Effects of exposure to direct sunlight on the mean volumetric moisture content of the soil at four monitoring depths approximately 7 days after watering to field capacity from July to early October.

sweetgum and water oak after the termination of replanting. Light regime affected height and groundline diameter for both species (figure 4). There was no difference between the two species for height (P=0.34), but the species differed for diameter (P=0.0001). Light regime and species interacted significantly for height (P=0.03), but did not interact significantly for groundline diameter (P=0.38). Seedling height and groundline diameter of both sweetgum and water oak generally increased with

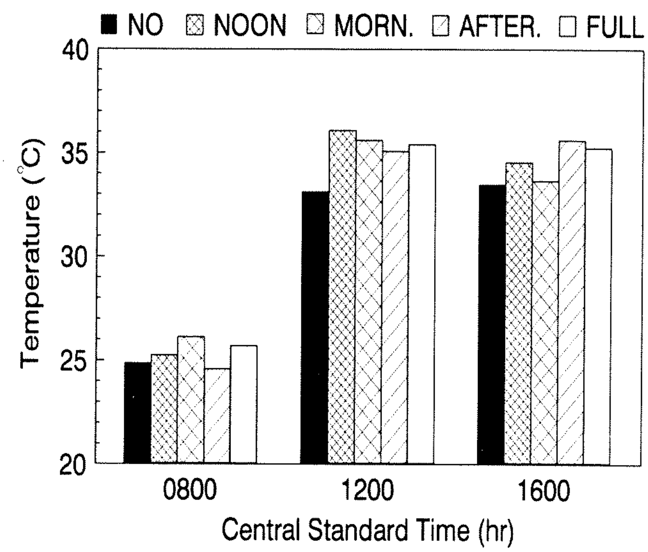

Figure 2—Effects of exposure to direct sunlight on mean air temperature in the morning, at noon, and in the afternoon from July through October.

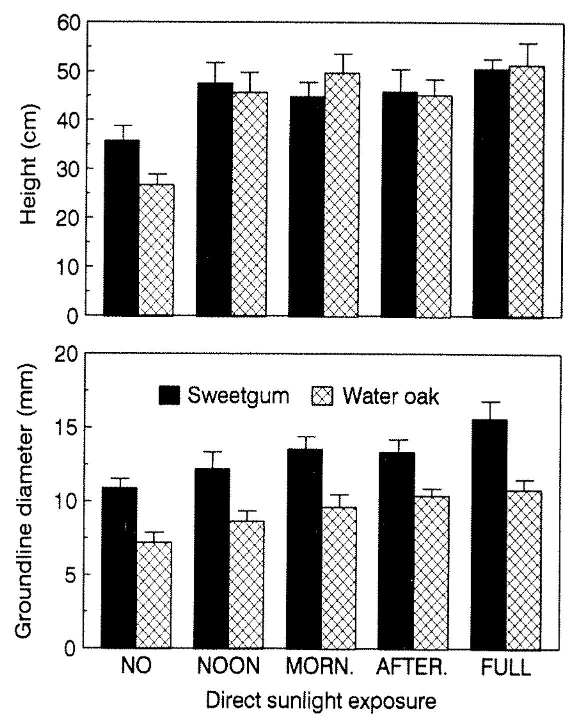

Figure 4—Effects of exposure to direct sunlight on mean height and groundline diameter (plus one standard error) of sweetgum and water oak seedlings at the end of the first growing season.

increasing exposure to direct sunlight. For both species, the most distinctive difference for height was between the NO treatment and the other treatments which received some direct sunlight exposure. With some direct sunlight, there was little difference between the height of sweetgum and water oak, but sweetgum was 35 percent taller than water oak for the NO treatment. Sweetgum consistently had larger groundline diameters than water oak. We observed that water oak would temporarily bend over because of its slender stem when leaves were wet. The difference in height and groundline diameter growth of sweetgum and water oak probably reflects some inherent difference in the early growth pattern of the two species.

Leaf morphology also reflected the differences in exposure to direct sunlight (table 1). For surface area, weight, and specific leaf area (SLA), significant differences occurred for both species and light regime treatments ($P<0.01$). The interaction of species and light regimes was significant for area and SLA ($P=0.0001$) but not for weight ($P=0.74$). The leaves of sweetgum were much larger than those of water oak, by an average of 2.2 times for weight and 2.9 times for area. The SLA of sweetgum and water oak was the same for the FULL treatment (about 100 square centimeters per gram), but the SLA of sweetgum exceeded that of water oak when direct sunlight exposure declined. For the NO treatment, the SLA of sweetgum exceeded that of water oak by 43 percent. Water oak appeared to be less adaptive to reduced exposure of direct sunlight than sweetgum.

CONCLUSION

Although light regime did not affect survival, seedlings exposed to full or partial direct sunlight had higher growth rates during the first growing season than seedlings that did not receive direct sunlight. Thus, the size of forest openings or overstory coverage will be important to provide adequate direct sunlight exposure for seedling development. By producing leaves with a higher SLA, sweetgum appeared to be more adaptive to increasing levels of shade than water oak. Thus, early results of our study suggest that high levels of sunlight are important for water oak to be competitive with sweetgum, especially in early height growth. Since the highest levels of shade occur along the southern edge of small forest openings, this is where water oak will be at a competitive disadvantage with sweetgum. The water-use efficiency was less for treatments receiving high levels of direct sunlight, and the results of our study may have been different had we not controlled competing herbaceous vegetation or provided supplemental water.

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